

UNCLASSIFIED

AD NUMBER	
AD370030	
CLASSIFICATION CHANGES	
TO:	UNCLASSIFIED
FROM:	SECRET//RESTRICTED DATA
LIMITATION CHANGES	
TO: Approved for public release; distribution is unlimited.	
FROM: Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; JAN 1962. Other requests shall be referred to Aeronautical Systems Division, Wright-Patterson AFB, OH 45433. Restricted Data.	
AUTHORITY	
OSD/WHS memo dtd 17 Mar 2016; OSD/WHS memo dtd 17 Mar 2016	

THIS PAGE IS UNCLASSIFIED



DEPARTMENT OF DEFENSE  
WASHINGTON HEADQUARTERS SERVICES  
1155 DEFENSE PENTAGON  
WASHINGTON, DC 20301-1155



MAR 17 2016

MEMORANDUM FOR DEFENSE TECHNICAL INFORMATION CENTER  
(ATTN: DTIC-OQ INFORMATION SECURITY)  
8725 JOHN J. KINGMAN ROAD, SUITE 0944  
FORT BELVOIR, VA 22060-6218

SUBJECT: OSD MDR Case 13-M-3705

We have reviewed the attached document in consultation with the Department of Energy and Department of the Air Force and have declassified it in full. If you have any questions please contact Mr. John D. Smith by phone at 571-372-0482 or by email at [john.d.smith887.civ@mail.mil](mailto:john.d.smith887.civ@mail.mil), [john.d.smith887.civ@mail.smil.mil](mailto:john.d.smith887.civ@mail.smil.mil), or [john.smith@osdj.ic.gov](mailto:john.smith@osdj.ic.gov).

George R. Sturgis  
Deputy Chief, Records and Declassification  
Division

Attachments:

1. MDR request w/ document list
2. Document 7





#7

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

DEPARTMENT OF ENERGY DECLASSIFICATION REVIEW	
1 <sup>st</sup> Review Date: Oct 17, 2013	DETERMINATION (CIRCLE NUMBER(S))
Authority: <input type="checkbox"/> DC <input checked="" type="checkbox"/> DD	1. CLASSIFICATION RETAINED
Name: G W Brothers	2. CLASSIFICATION CHANGED TO: NSI
2 <sup>nd</sup> Review Date: 10/24/2013	3. CONTAINS NO DOE CLASSIFIED INFO
Authority: DD	4. COORDINATE WITH:
Name: S. Fivozinsky	5. CLASSIFICATION CANCELED
	6. CLASSIFIED INFO BRACKETED
	7. OTHER (SPECIFY):

## SECURITY MARKING

~~The classified or limited status of this report applies to each page, unless otherwise marked.~~  
~~Separate page printouts MUST be marked accordingly.~~

~~THIS DOCUMENT CONTAINS INFORMATION AFFECTING THE NATIONAL DEFENSE OF THE UNITED STATES WITHIN THE MEANING OF THE ESPIONAGE LAWS, TITLE 18, U.S.C., SECTIONS 793 AND 794. THE TRANSMISSION OR THE REVELATION OF ITS CONTENTS IN ANY MANNER TO AN UNAUTHORIZED PERSON IS PROHIBITED BY LAW.~~

~~NOTICE: When government or other drawings, specifications or other data are used for any purpose other than in connection with a definitely related government procurement operation, the U. S. Government thereby incurs no responsibility, nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use or sell any patented invention that may in any way be related thereto.~~

Office of the Secretary of Defense  
Chief, RDD, ESD, WHS  
Date: 29 MAY 2015 Authority: EO 13526  
Declassify: X Deny in Full: \_\_\_\_\_  
Declassify in Part: \_\_\_\_\_  
Reason: \_\_\_\_\_  
MDR: 13-M-3705

5 U.S.C. 552

R-5  
13-M-3705





~~SECRET~~ - Restricted Data  
~~Atomic Energy Act of 1954~~

370030



FACILITY FORM 903

(ACCESSION NUMBER)	(YEAR)
355	55
(PAGES)	(CODE)
(NADA CR OR TMA OR AU NUMBER)	(CATEGORY)

AD NO 370030  
MIC FILE COPY

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

THE  
**Marquardt**  
CORPORATION

VAN NUYS, CALIFORNIA

~~SECRET~~ - Restricted Data  
~~Atomic Energy Act of 1954~~

115-155

31

30 JANUARY, 1962

✓ REPORT 5876 ✓

COPY NO. 52

✓

(TITLE -- UNCLASSIFIED)  
ANNUAL REPORT FOR 1961  
NUCLEAR RAMJET PROPULSION SYSTEM  
PROJECT PLUTO

*Contract AF 33(616)-7857*

28578

Page determined to be Unclassified  
Reviewed Chief, RDD, WHS  
IAW EO 13526, Section 3.5  
Date: MAY 29 2015

DDC 6 CONTROL  
NO. 858



DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

DATE <sup>(11)</sup> 30 Jan 1962, <sup>(12)</sup> 346 p.

REC <sup>(14)</sup> 5876

Number of Pages: 346 and xviii

~~RESTRICTED DATA~~

~~THIS DOCUMENT CONTAINS RESTRICTED DATA AS DEFINED IN THE ATOMIC ENERGY ACT OF 1954. ITS TRANSMISSION OR THE DISCLOSURE OF ITS CONTENTS IN ANY MANNER TO AN UNAUTHORIZED PERSON IS PROHIBITED.~~

~~SECRET RESTRICTED DATA~~  
~~ATOMIC ENERGY ACT OF 1954~~

~~EXCLUDED FROM AUTOMATIC  
REGRADING: DOD DIR 5200.10  
DOES NOT APPLY~~

(Title -- Unclassified)

<sup>(9)</sup> ANNUAL REPORT ~~FOR THE~~ 1 Feb-31 J ac 64.  
<sup>(6)</sup> NUCLEAR RAMJET PROPULSION SYSTEM  
PROJECT PLUTO <sup>(2)</sup> <sup>(8)</sup>

~~SECRET~~ <sup>(15)</sup> AF 33(616)-7857 ✓  
~~SECRET~~ <sup>(16)</sup> AF-254

APPROVED BY

*A. O. Mooneyham*  
A. O. Mooneyham, Jr.  
Senior Project Engineer,  
Pluto Project

~~This document contains information affecting the National Defense of the United States within the meaning of the Espionage Laws, Title 18, U.S.C., Sec. 793 and 794, and the transmission or the revelation of its contents in any manner to an unauthorized person is prohibited by law.~~

~~SECRET RESTRICTED DATA~~  
~~ATOMIC ENERGY ACT OF 1954~~

is any	DATE	9.5	CONTROL
E	9.5	9.5	
C	9.5	9.5	
R	9.5	9.5	
E	Copy No.	5	

MAC 1179  
28398

THE *Marquardt* CORPORATION  
VAN NUYS, CALIFORNIA (218 350)

Previous page was blank, therefore not filmed.

DATE 30 Jan 1962,

(13) 346 p.

REI ST 5876

Number of Pages: 346 and xviii

~~RESTRICTED DATA~~

~~THIS DOCUMENT CONTAINS RESTRICTED DATA AS DEFINED IN THE ATOMIC ENERGY ACT OF 1954. ITS TRANSMITTAL OR THE DISCLOSURE OF ITS CONTENTS IN ANY MANNER TO AN UNAUTHORIZED PERSON IS PROHIBITED.~~

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

~~EXCLUDED FROM AUTOMATIC  
REGRADING: DOE DIR 5200.10  
DOES NOT APPLY~~

(Title -- Unclassified)

(9) ANNUAL REPORT, 1 Feb-31 Dec 61.  
(6) NUCLEAR RAMJET PROPULSION SYSTEM  
PROJECT PLUTO (21) (8)

Contract

(15) AF/33(616)-7857 ✓

Report

(16) AF-254

APPROVED BY

*A. O. Mooneyham Jr.*  
A. O. Mooneyham Jr.  
Senior Project Engineer,  
Pluto Project

~~This document contains information affecting the national defense of the United States within the meaning of the espionage laws, the transmission or the revelation of its contents in any manner to an unauthorized person is prohibited by law.~~

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

THE  
*Marquardt*  
CORPORATION

VAN NUYS, CALIFORNIA

(218 350)

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Reglass Div, WHS  
Date: MAY 29 2015

MAC 47798

28398

C  
O  
N  
T  
R  
O  
L

Previous page was blank, therefore not filmed.

~~SECRET RESTRICTED DATA~~

*THE Marquardt*  
CORPORATION  
VAN NUYS, CALIFORNIA

RI RT 5876

~~ATOMIC ENERGY ACT OF 1954~~

#### FOREWORD

This report is submitted in compliance with applicable paragraphs of Air Force Contract AF 33(616)-7857 for the period 1 February through 31 December 1961.

#### ABSTRACT

Results of studies conducted during the period 1 February through 31 December 1961 on Project Pluto are presented. A major portion of discussion is directed toward integration of the components of the propulsion system. Included are the results of studies involving mechanical design and structural analyses, performance evaluation, materials research, control system analysis, and facilities planning investigations.

(Unclassified Abstract)

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

Previous page was blank, therefore not filmed.



~~SECRET RESTRICTED DATA~~

RI 87 5876

~~ATOMIC ENERGY ACT OF 1954~~

CONTENTS

Section	Page
Foreword .....	v
Abstract .....	v
1.0 Introduction .....	1
2.0 Summary .....	3
3.0 Propulsion System Design and Analysis .....	7
3.1 Tory IIC Design Data, .....	7
3.2 Performance Analysis, .....	7
3.3 Engine Performance Summary, (Performance Bulletin No. 4) .....	68
3.4 Heat Transfer and Thermal Stress Analysis, .....	90
3.5 Mechanical and Structural Design, .....	120
3.6 Neutronics, .....	136
3.7 Radiation Analysis and Shielding, .....	157
3.8 Aerodynamic Experiments, .....	172
3.9 Structural Experiments, and .....	217
3.10 Materials Investigations, .....	222
4.0 Propulsion System Controls .....	261
4.1 General Status, .....	261
4.2 Control System Analysis, .....	261
4.3 Control System Components, and .....	269
4.4 Radiation Effects Testing, .....	297
5.0 Flight Engine Facility and Test Planning .....	302
5.1 Facility Design Studies, and .....	302
5.2 Underground Air Storage Experiment .....	323
References .....	339

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~



Previous page was blank, therefore not filmed.



~~SECRET RESTRICTED DATA~~

VAN NUYS, CALIFORNIA

REF ID: A5876

~~ATOMIC ENERGY ACT OF 1954~~

## ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
1.	Estimated Performance of Basic Inlet for MA50-XCA Engine . . . . .	10
2.	Estimated Thrust Coefficient of MA50-XCA Ramjet at Altitude of 1000 Feet . . . . .	12
3.	Estimated Thrust Coefficient of MA50-XCA Ramjet at Altitude of 30,000 Feet . . . . .	13
4.	Inlet Pressure Recovery of MA50-XCA Ramjet at Altitude of 1000 Feet . . . . .	14
5.	Inlet Pressure Recovery of MA50-XCA Ramjet at Altitude of 30,000 Feet . . . . .	15
6.	Free Stream Capture Area Ratio of MA50-XCA Ramjet at Altitude of 1000 Feet . . . . .	16
7.	Free Stream Capture Area Ratio of MA50-XCA Ramjet at Altitude of 30,000 Feet . . . . .	17
8.	Drag of MA50-XCA Ramjet Engine Installation at Altitude of 1000 Feet . . . . .	18
9.	Drag of MA50-XCA Ramjet Engine Installation at Altitude of 30,000 Feet . . . . .	19
10.	Effect of Inlet Pressure Recovery of MA50-XCA Ramjet at Altitude of 1000 Feet . . . . .	20
11.	Effect of Inlet Pressure Recovery of MA50-XCA Ramjet at Altitude of 30,000 Feet . . . . .	21
12.	Estimated Thrust Coefficient of MA50-XCA Ramjet (ANA Hot Day) . . . . .	22
13.	Effect of Wall Temperature on Net Jet Thrust Coefficient at Design Point . . . . .	23
14.	Estimated Thrust Coefficient (ICAO Standard Day) . . . . .	25
15.	Inlet Pressure Recovery (ICAO Standard Day) . . . . .	26
16.	Effect of Reactor Diameter Increase on Net Jet Thrust Coefficient (Performance Bulletin No. 2) . . . . .	28
17.	Effect of Reactor Diameter Increase on Net Jet Thrust Coefficient . . . . .	31
18.	Marquardt Model MA50-XDA Ramjet Estimated Thrust Coefficient for $T_{wmax} = 2960^{\circ} R$ (Altitude = 1000 Feet) . . . . .	32
19.	Marquardt Model MA50-XDA Ramjet Estimated Thrust Coefficient for $T_{wmax} = 2960^{\circ} R$ (Altitude = 30,000 Feet) . . . . .	33
20.	Marquardt Model MA50-XDA Ramjet Inlet Pressure Recovery (Altitude = 1000 Feet) . . . . .	34

MAC 167

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

DECLASSIFIED IN FULL  
Authority: EO 13526

ix Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

ILLUSTRATIONS (Continued)

<u>Figure</u>		<u>Page</u>
21.	Marquardt Model MA50-XDA Ramjet Inlet Pressure Recovery (Altitude = 30,000 Feet) . . . . .	15
22.	Marquardt Model MA50-XDA Ramjet Free Stream Capture Area Ratio . . . . .	16
23.	Marquardt Model MA50-XDA Ramjet Drag of Engine Installation (Altitude = 1000 Feet) . . . . .	17
24.	Marquardt Model MA50-XDA Ramjet Drag of Engine Installation (Altitude = 30,000 Feet) . . . . .	18
25.	Comparison of Relative Power Profiles . . . . .	19
26.	Axisymmetric, External-Internal Compression Inlet . . . . .	13
27.	Optimization of Mach 2.8 Axisymmetric Inlet . . . . .	14
28.	Variable Inlet Operation at 0° Angle of Attack and Yaw . . . . .	15
29.	Variation of Inlet Area Ratio with Spike Translation . . . . .	17
30.	Comparison of Inlet Types . . . . .	18
31.	Typical Exhaust Nozzle Installations . . . . .	19
32.	Nozzle-Boattail Optimization for MA50-XCA Engine at Design Point . . . . .	31
33.	Forced Convection Configuration of Exhaust Nozzle . . . . .	33
34.	Ejector Configuration of Exhaust Nozzle . . . . .	34
35.	Diagram of Annular, Forced Convection Nozzle Exhaust System . . . . .	39
36.	Diagram of Tubular, Forced Convection Nozzle Exhaust System . . . . .	30
37.	Diagram of Ejector Nozzle Exhaust System . . . . .	32
38.	Diagram of Radiation Cooled Nozzle Exhaust System . . . . .	34
39.	Propulsion System MA50-XCA Preliminary Layout . . . . .	75
40.	Comparison of Relative Core Power Profiles . . . . .	34
41.	Estimated ANA Hot Day Operating Envelope for the Marquardt Model MA50-XCA Ramjet . . . . .	36
42.	Estimated ANA Cold Day Operating Envelope for the Marquardt Model MA50-XCA Ramjet . . . . .	37
43.	Estimated ICAO Standard Day Operating Envelope for the Marquardt Model MA50-XCA Ramjet . . . . .	38
44.	Preliminary Estimates of Steady-State Temperatures in the MA50-XCA Propulsion System Inlet . . . . .	91
45.	Steady-State Temperatures in a Tory IIC Tie Tube and Surrounding Beryllia at Design Point Conditions . . . . .	93
46.	Tory IIC Tie Tube Configuration and Analytical Models . . . . .	95

MAC 1673

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

x

DECLASSIFIED IN FULL

Authority: EO 13526

Chief, Records & Declass Div, WHS

Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

RE BY

~~ATOMIC ENERGY ACT OF 1954~~

ILLUSTRATIONS (Continued)

<u>Figure</u>		<u>Page</u>
47.	Wire-Wrapped Tubular Nozzle . . . . .	97
48.	Tubular Wire-Wrapped Configurations for Pluto Engine Exhaust Nozzle . . . . .	98
49.	Nozzle-Tube Maximum Temperature and Total Nozzle-Tube Weight . . . . .	99
50.	Steady-State Temperatures in a Pluto Engine Exhaust Nozzle . . . . .	100
51.	Steady-State Temperatures of Wire-Wrapped Tubular Exhaust Nozzle at Mach 2.8, 1,000 Feet, ANA Cold Day, 626-Mw Reactor Power Level . . . . .	103
52.	Steady-State Temperatures of Wire-Wrapped Tubular Exhaust Nozzle at Mach 2.8, 1,000 Feet, ANA Hot Day, 516-Mw Reactor Power Level . . . . .	104
53.	Physical Dimensions of Exhaust Nozzle Cooling Tube . . . . .	105
54.	Steady-State Temperatures of Wire-Wrapped Tubular Exhaust Nozzle of MA50-XCA Propulsion System . . . . .	106
55.	Maximum Steady-State Metal Temperatures in an Ejector or Film-Cooled Nozzle for the MA50-XCA Propulsion System . . . . .	108
56.	Exhaust-Nozzle-to-Reactor-Shell Attachment . . . . .	109
57.	Steady-State Temperature Profile for Nozzle Attachment Fitting . . . . .	110
58.	Analytical Model for Determination of Propulsion System Heat Rejection . . . . .	111
59.	Steady-State Temperatures in MA50-XCA Propulsion System and Airframe . . . . .	113
60.	Steady-State Temperatures in MA50-XDA Propulsion System and Airframe . . . . .	115
61.	Maximum Elastic Thermal Stress (Tensile) in a Tory IIC Fueled Tube . . . . .	117
62.	Material Temperature Difference in Tory IIC Fueled Tube . . . . .	118
63.	Steady-State Temperatures and Maximum Elastic Thermal Stress (Tensile) in a Tory IIC Fueled Tube . . . . .	119
64.	Steady-State Temperatures for Nutating Disk Motor of Control Rod Actuator . . . . .	121
65.	Steady-State Temperatures for Gear Train of Control Rod Actuator . . . . .	122

MAC 4273

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

DECLASSIFIED IN FULL

Authority: EO 13526

Chief, Records & Declass Div, WHS

Date: MAY 29 2015



~~SECRET RESTRICTED DATA~~

REPORT 587

~~ATOMIC ENERGY ACT OF 1954~~

# ILLUSTRATIONS (Continued)

Figure	Page
66. Nuclear Heating in Control Rod Actuator . . . . .	1
67. Belleville Spring in Reactor Lateral Support Structure . . . . .	1
68. Tangential Spring System and Idealized Model . . . . .	1
69. Propulsion System MA50-XCA . . . . .	1
70. Axisymmetric Inlet . . . . .	1
71. Axisymmetric Inlet No. 2 . . . . .	1
72. Proposed Ballscrew Actuator . . . . .	1
73. Exhaust Nozzle Assembly Ejector . . . . .	1
74. Geometry and Physical Data for Angle Neutronics Model (Problem I. D. Toy 004) . . . . .	1
75. Power and Fuel Distribution for Final Angle Neutronics Model (Problem I. D. Toy 004) . . . . .	1
76. Maximum Neutron Leakage Current Spectra (Problem I. D. Toy 004) . . . . .	1
77. Axial Power Correlation for Angle Neutronics Models of the Tory IIC Reactor (Isothermal Wall - 2500° F) . . . . .	1
78. Power and Fuel Distribution for Final Angle Neutronics Model, Isothermal Core (Problem I. D. Iso 003) . . . . .	1
79. Maximum Neutron Leakage Current Spectra (Problem I. D. Iso 003) . . . . .	1
80. Geometry and Physical Data for Angle Neutronics Model (Problem I. D. Big 002) . . . . .	1
81. Power and Fuel Distribution for Final Angle Neutronics Model (Problem I. D. Big 002) . . . . .	1
82. Geometry and Physical Data for Angle Neutronics Model (Problem I. D. BST 005) . . . . .	1
83. Power and Fuel Distribution for Final Angle Neutronics Model (Problem I. D. BST 005) . . . . .	1
84. Geometry and Physical Data for Final Angle Neutronics Model MA50-XDA (Problem I. D. Fin 003) . . . . .	1
85. Power and Fuel Distribution for Final Angle Neutronics Model MA50-XDA (Problem I. D. Fin 003) . . . . .	1
86. Maximum Neutron Leakage Flux Spectra (Problem I. D. Fin 003) . . . . .	1
87. Initial Multiplication Factor as a Function of Reactor Life . . . . .	1
88. Gamma and Neutron Isodose Curves . . . . .	1

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~



~~SECRET RESTRICTED DATA~~

DET 5876

~~ATOMIC ENERGY ACT OF 1954~~

ILLUSTRATIONS (Continued)

<u>Figure</u>		<u>Page</u>
89.	Neutron and Gamma Dose Rates as a Function of Distance Forward of Reactor Center . . . . .	160
90.	Idealized Configuration of Tory IIC Reactor With and Without Peripheral Shims . . . . .	164
91.	Distribution of (n, $\gamma$ ) Reaction . . . . .	166
92.	Radial Distribution of Heating from Each Gamma Component . . . . .	167
93.	Distribution of Total Gamma Heating . . . . .	168
94.	Nuclear Heating for End Reflectors . . . . .	170
95.	Nuclear Heating for Side Reflector Along R = 67.62 . . . . .	171
96.	Inlet Model During Assembly . . . . .	175
97.	Cowl and Center Body of Inlet Model . . . . .	176
98.	Exhaust Nozzle Models . . . . .	177
99.	Contours of Primary Nozzles . . . . .	178
100.	Contours of Forced Convection and Ejector Nozzles . . . . .	179
101.	Static Thrust Facility at FluidDyne Elk River Aerodynamics Laboratory . . . . .	180
102.	Thrust Coefficients from Tests of Primary Nozzles . . . . .	183
103.	Thrust Coefficient of Forced Convection Nozzle (Model FC-3) . . . . .	184
104.	Thrust Coefficient of Ejector Nozzle (Model E-1) . . . . .	185
105.	Nozzle Wall Pressure Distribution . . . . .	187
106.	Shadowgraph of Exhaust Flow from Forced Convection Nozzle at Design Pressure Ratio . . . . .	188
107.	Comparison of Profile Straightening Characteristics MA50XA-1 at Design Point . . . . .	190
108.	Bulldup of Simulated Reactor Segment for Aerodynamic Coupling Test . . . . .	192
109.	Completion of Bulldup of Tubes in Simulated Reactor Segment . . . . .	193
110.	Aft Plate with Instrumentation and Tubes Used to Build Up Simulated Reactor Segment . . . . .	194
111.	Simulated Reactor Segment Installed in 18-Inch Duct . . . . .	195
112.	Schematic of Coupling Test Instrumentation . . . . .	197
113.	Aerodynamic Coupling Test Setup in Test Cell . . . . .	198
114.	Aerodynamic Coupling Test Duct Static and Total Pressure Profiles Measured Upstream from Tube Bundle Entrance . . . . .	200
115.	Aerodynamic Coupling Test Duct Static and Total Pressure Profiles Measured Upstream from Tube Bundle Entrance (Run 15) . . . . .	201

MAC 603

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~



~~SECRET RESTRICTED DATA~~

REPORT 5 6

~~ATOMIC ENERGY ACT OF 1954~~

ILLUSTRATIONS (Continued)

<u>Figure</u>	<u>Page</u>
116. Air Flow and Pressure Distortions Measured at Tube Bundle Exit (Run 11) . . . . .	13
117. Air Flow and Pressure Distortions Measured at Tube Bundle Exit (Run 15) . . . . .	14
118. Aerodynamic Coupling Test Duct Static and Total Pressure Profiles Measured Upstream from Tube Bundle Entrance (Run 12) . . . . .	15
119. Aerodynamic Coupling Test Duct Static and Total Pressure Profiles Measured Upstream from Tube Bundle Entrance (Run 14) . . . . .	16
120. Air Flow and Pressure Distortions Measured at Tube Bundle Exit (Run 12) . . . . .	17
121. Air Flow and Pressure Distortions Measured at Tube Bundle Exit (Run 14) . . . . .	18
122. Aerodynamic Coupling Test Duct Static and Total Pressure Profiles Measured Upstream from Tube Bundle Entrance (Run 13) . . . . .	19
123. Air Flow and Pressure Distortions Measured at Tube Bundle Exit (Run 13) . . . . .	20
124. Imposed Pressure Profile Distortion Analysis . . . . .	21
125. Air Flow and Pressure Distortion Data for Design Coupling Length (Run 17) . . . . .	23
126. Air Flow and Pressure Distortion Data for Minimum Coupling Length (Run 16) . . . . .	24
127. Effect of Coupling Length on Distortion . . . . .	25
128. Recorded Noise and Vibration Data . . . . .	26
129. Air Flow Leakage Results of Nozzle Attachment Test . . . . .	28
130. Test Item for Exit Nozzle Attachment Test . . . . .	29
131. Exit Nozzle Attachment Test Item in Ground Pit . . . . .	31
132. Corrugated Springs in Reactor Lateral Support Structure . . . . .	33
133. Lateral Attachment Test Items . . . . .	35
134. 1% Creep of R-235 Alloy Sheet: Comparison of Parent Metal and Fusion Welds . . . . .	39
135. 1% Creep of R-235 Alloy Plate: Comparison of Parent Metal and Fusion Welds . . . . .	40
136. 1% Creep of Rene' 41 Alloy Sheet: Comparison of Parent Metal and Fusion Welds . . . . .	41

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

~~SECRET RESTRICTED DATA~~

RI INT 5876

~~ATOMIC ENERGY ACT OF 1954~~

ILLUSTRATIONS (Continued)

<u>Figure</u>		<u>Page</u>
137.	1% Creep of Rene' 41 Alloy Plate: Comparison of Parent Metal and Fusion Welds . . . . .	242
138.	Tensile Properties of Type 321 Stainless Steel Sheet . . . . .	243
139.	Beryllia Hydrolysis Specimen L-6 (After Exposure) . . . . .	246
140.	Atomics International Hot Pressed Beryllia in Test Module (Aft End) Before Shock Test . . . . .	248
141.	Ten-Spring Stack of Belleville Springs . . . . .	250
142.	Belleville Spring Tester . . . . .	251
143.	Belleville Spring Tester with Vibrator Installed . . . . .	253
144.	Corrugated Side Support Springs . . . . .	255
145.	Corrugated Side Support Springs Installed in Baldwin Universal Test Machine Showing Strain Gage Instrumentation . . . . .	256
146.	Elevated Temperature Test of Corrugated Side Support Spring . . . . .	257
147.	1400° F Test of Corrugated Spring in Elevated Temperature Test Machine . . . . .	258
148.	Plate Springs with Test Fixture for Temperature and Compression Testing . . . . .	260
149.	Reactor Power - Real Time Profile . . . . .	265
150.	Airframe Transient Response During Period of Inlet Unstart and Restart . . . . .	267
151.	Net Drag Coefficient for Unstarted Inlet and Net Thrust and Drag Coefficients for Started Inlet . . . . .	268
152.	Gamma Ion Chamber Characteristics . . . . .	271
153.	Neutron Ion Chamber Characteristics . . . . .	272
154.	Neutron Chamber - Gamma Chamber Current Ratio . . . . .	274
155.	Calibration of Experimental Platinum Wire Resistance Sensor . . . . .	277
156.	Four-Inch-Stroke Actuator Installed in Environmental Oven . . . . .	279
157.	Closed Loop Frequency Response of Actuator with Forward Loop Gain Increased by Factor of Five (Test Data at 1070° F) . . . . .	280
158.	Closed Loop Frequency Response of Actuator with Forward Loop Gain Increased by Factor of Five (Test Data at Ambient Temperature) . . . . .	281

MAC 1453

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~





~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

ILLUSTRATIONS (Continued)

<u>Figure</u>		<u>Page</u>
159.	Forty-Inch-Stroke Actuator . . . . .	28
160.	Resolution of Forty-Inch-Stroke Actuator . . . . .	28
161.	Transient Response of Forty-Inch-Stroke Actuator . . . . .	28
162.	Experimental Temperature Control and Reactor Compensation Loops . . . . .	29
163.	Diagram of 400 cps Second Harmonic, d-c Magnetic Amplifier . . . . .	29
164.	Diagram of 4800 cps Push-Pull, d-c Magnetic Amplifier . . . . .	29
165.	Data Handling Equipment Used to Check Circuits . . . . .	30
166.	Site Selection Study . . . . .	30
167.	Pressure Drop Characteristics of 10 3/4 Inch Casing From Underground Air Storage Chamber . . . . .	30
168.	Vitiated Air Heater . . . . .	31
169.	Comparison of Cost of Four-Million-Pound Liquid Air System with Cost of Underground Air Storage . . . . .	31
170.	Comparison of Cost of Eleven-Million-Pound Liquid Air System with Cost of Underground Air Storage . . . . .	31
171.	Comparison of Cost of Twenty-Seven-Pound Liquid Air System with Cost of Underground Air Storage . . . . .	31
172.	Continuous Air Compressing System Costs . . . . .	31
173.	Two-Chamber Underground Storage . . . . .	32
174.	UAS Chamber Vicinity Map Including Plot Plan and Core Hole Locations . . . . .	32
175.	Typical Core Samples and Drilling Operations for UAS Experiment . . . . .	32
176.	UAS Pilot Chamber . . . . .	32
177.	Analytical Model of Liner-Rock Deflection . . . . .	32
178.	Rock Loading for Underground Air Storage Chamber Steel Liner Thickness = 0.161 Inch . . . . .	33
179.	Rock Loading for Underground Air Storage Chamber Steel Liner Thickness = 0.187 Inch . . . . .	33
180.	Rock Loading for Underground Air Storage Chamber Steel Liner Thickness = 0.438 Inch . . . . .	33
181.	Rock Loading for Underground Air Storage Chamber Steel Liner Thickness = 1.12 Inches . . . . .	33
182.	UAS Chamber Instrumentation . . . . .	33
183.	Transducer Rods of UAS Chamber Instrumentation . . . . .	33

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

MAC 163



DECLASSIFIED IN FULL

Authority: EO 13526

Chief, Records & Declass Div, WHS

Date: MAY 29 2015



~~SECRET RESTRICTED DATA~~

BI RT 5876

~~ATOMIC ENERGY ACT OF 1954~~

TABLES

	<u>Page</u>
1. Tory IIC Performance .....	8
2. Comparison of Aerothermodynamic Performance Characteristics at the Design Point .....	24
3. MA50-XDA Aerothermodynamic Performance Characteristics at the Design Point .....	30
4. Forced Convection Configurations .....	52
5. Weights for Flight Type Tory IIC Reactor .....	78
6. Heat Rejection of MA50-XDA Propulsion System .....	80
7. Comparison of Aerothermodynamic Parameters for Various Modifications to Basic Model MA50-XCA Propulsion System at Design Point .....	81
8. Conditions Used in Tory IIC Tie-Tube Heat Transfer Study .....	94
9. Conditions of Heat Transfer Study of MA50-XCA Exhaust Nozzle .....	102
10. Heat Rejection of MA50-XCA Propulsion System .....	114
11. Angle Energy Group Limits .....	142
12. Gamma Flux Densities Outside Tory IIC Reactor Core .....	162
13. Neutron Spectra for One Watt of Power .....	163
14. Test Conditions for Vibration of Simulated Reactor Core Section .....	224
15. Comparative Short Time Tensile Properties of Hastelloy R-235 Alloy Sheet Base and Welded Material .....	226
16. Comparative Creep and Rupture Properties of Hastelloy R-235 Alloy Sheet Base and Welded Material .....	227
17. Comparative Short Time Tensile Properties of Hastelloy R-235 Alloy Plate Base and Welded Material .....	228
18. Comparative Creep and Rupture Properties of Hastelloy R-235 Alloy Plate Base and Welded Material .....	229
19. Comparative Short Time Tensile Properties of Rene' 41 Alloy Sheet Base and Welded Material .....	230

MAC 403

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

DECLASSIFIED IN FULL

Authority: EO 13526

Chief, Records & Declass Div, WHS

Date: MAY 29 2015



REPORT 5876

~~SECRET RESTRICTED DATA~~

ATOMIC ENERGY ACT OF 1954

TABLES (Continued)

	<u>Pa</u>
20. Comparative Creep and Rupture Properties of Rene' 41 Alloy Sheet Base and Welded Material . . . . .	23
21. Comparative Short Time Tensile Properties of Rene' 41 Alloy Plate Base and Welded Material . . . . .	23
22. Comparative Creep and Rupture Properties of Rene' 41 Alloy Plate Base and Welded Material . . . . .	23
23. Comparative Short Time Tensile Properties of AISI Type 321 Stainless Steel Sheet, Base, and Welded Material . . . . .	23
24. Short Time Tensile Properties of Inco 713C Alloy . . . .	23
25. Creep and Rupture Properties of Inco 713C Alloy . . . .	23
26. Short Time Tensile Test Properties of Hastelloy C Alloy Plate - Air Melted . . . . .	23
27. Creep and Rupture Properties of Hastelloy C Alloy Plate - Air Melted . . . . .	23
28. Amplifier Characteristics . . . . .	29
29. Characteristics of Cross-Country Deployment of Tory IIC Air Storage Addition . . . . .	30
30. Summary of Facility Costs . . . . .	31

~~SECRET RESTRICTED DATA~~

ATOMIC ENERGY ACT OF 1954



~~SECRET RESTRICTED DATA~~

ORT 5876

~~ATOMIC ENERGY ACT OF 1954~~

## 1.0 INTRODUCTION

The Marquardt Corporation, under U. S. Air Force Contract AF33 (616)-7857, is engaged in a program of applied research on nuclear ramjet propulsion systems (Project Pluto). This report summarizes technical progress for the period 1 February 1961 through 31 December 1961.

Under the provisions of the contract, Marquardt is responsible for the technological advancement of propulsion system nonnuclear components necessary to the ultimate design, development, and testing of a flight prototype nuclear ramjet engine. Lawrence Radiation Laboratory, under AEC contract, has responsibility for development of a flight-worthy reactor. An important program milestone was achieved in 1961 with the successful operation of the Tory II A reactor. Designed and built by the Lawrence Radiation Laboratory (LRL), the Tory II A reactor achieved or surpassed all design and test objectives, thereby establishing the feasibility of a high power density, high-temperature, air-cooled reactor. The flight-type reactor, designed Tory II C, is presently being fabricated by LRL and is scheduled for testing early in 1963.

As propulsion system contractor for the Air Force, Marquardt's efforts during 1961 were directed toward establishing performance and preliminary design of an integrated propulsion system based on the Tory II C reactor.

Sufficient analytical and experimental data have been accumulated to describe a propulsion system capable of fulfilling a prescribed Air Force mission (ADO-11). As evidence of the potential offered by the Pluto propulsion system, the Air Force has elected in 1962 to pursue a program aimed at early ground testing of a flight prototype engine--the first major step toward the timely acquisition of a SLAM vehicle.

MAC 463

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

DECLASSIFIED IN FULL

Authority: EO 13526

Chief, Records & Declass Div, WHS

Date: MAY 29 2015

Previous page was blank, therefore not filmed.

SECRET-RESTRICTED DATA

*Marquardt*  
CORPORATION  
VAN NUYS, CALIFORNIA

ORT 5876

~~ATOMIC ENERGY ACT OF 1954~~

## 2.0 SUMMARY

Nuclear ramjet performance studies performed during 1961 were published in the form of four performance bulletins, Performance Bulletin No. 4 being an integral part (Section 3.3) of this summary report. The first bulletin presented preliminary design point performance characteristics of a propulsion system (designated the Marquardt Model MA50-XCA) utilizing the Tory IIC reactor. The second bulletin contained revised Model MA50-XCA performance characteristics consistent with newly acquired Tory IIC reactor data. In addition, the second bulletin described the performance effects associated with a 2500° F isothermal reactor wall temperature and the effects of increasing the Tory IIC reactor diameter. The diameter scaling effects were used by the aerothermodynamics contractor to perform a first iteration of the reactor size necessary to perform the ADO-11 mission. The basic Model MA50-XCA design point performance characteristics contained in the second bulletin listed the engine thrust as 39,700 pounds and the thrust coefficient as 0.200. For an isothermal wall, the thrust increased to 43,860 pounds and the thrust coefficient went up to 0.221.

Performance Bulletin No. 3 was devoted to the performance analysis of an engine capable of performing the ADO-11 mission. This propulsion system, with a reactor of increased diameter and decreased length, is identified as the Model MA50-XDA ramjet. The reactor diameter was increased from 57 to 63 inches, and 4 inches of the forward reflector and 4 inches of the aft fueled core were removed. The net jet thrust of the system is 50,000 pounds.

Performance Bulletin No. 4 represents a departure from previous bulletins in that it is devoted to the prediction of potential performance gains achieved through reasonable advancements in Tory IIC technology. Advancements included modifications in basic Tory IIC geometry and changes in design criteria. Optimization of reactor length, reduction in the number of tie rods, a change in fuel element tube diameter, modification of the power profile, and an increase in the beryllia elastic thermal stress limit are among the effects investigated. The most significant performance gains (up to 5 percent increase in thrust) were those resulting from changes in power profile and thermal stress limits.

Exit nozzle model tests were successfully completed, with experimental data being obtained for forced convection and ejector type nozzles. Nozzle velocity coefficients greater than 0.98 were documented for each nozzle configuration tested, thus verifying the value of 0.98 used in past performance studies, and supporting the conviction that the Model MA50-XCA performance characteristics are entirely realistic.

SECRET-RESTRICTED DATA

~~ATOMIC ENERGY ACT OF 1954~~





~~SECRET RESTRICTED DATA~~

REPORT 587

~~ATOMIC ENERGY ACT OF 1954~~

The aerodynamic coupling test, also successfully completed, verified within 5 percent the calculated effects of imposed pressure profiles on reactor tube weight flow distributions. The effects of reactor-nozzle coupling length were documented, and data were obtained that substantiate the effectiveness of the reactor as a flow straightener. On the basis of this test a slightly greater separation distance is required between reactor and nozzle.

The inlet model test program proceeded on schedule, up until mid-December 1961. Installation of the model in the Langley Field wind tunnel, originally scheduled for 18 December, was delayed by facility problems. Two inlet configurations will be tested, the basic Pluto inlet and an alternate inlet mutually agreed upon by Marquardt and the aerothermodynamics contractor. Initial experimental data will become available about 1 February, 1962.

The mechanical and structural problems concerning the installation and support of the reactor in a minimum diameter airframe have been investigated both analytically and experimentally. The concept of a lateral support system utilizing pre-loaded springs has been studied in the light of four different spring configurations. High-temperature deflection and vibration tests were performed on Belleville and corrugated springs, and an analysis of reactor vibration modes was made to aid in the establishment of design criteria and the specification of input data for test programs. An experimental vibration test is under way to evaluate proposed engine-airframe lateral attachment systems. In these tests a full scale 10-inch thick, lateral section containing a simulated core matrix, peripheral shell, and suspension system will be subjected to vibrational tests at typical operating temperatures (1300° F). The first system to be tested utilizes corrugated springs. Initial test results should be available about 1 March, 1962.

In the area of propulsion system controls, emphasis has been placed on high-temperature actuator and electronic component development. Sixty hours of ambient temperature testing and 1 1/2 hours of high-temperature testing (1000° F) were accumulated on the 40-inch-stroke high-speed pneumatic actuator. Closed loop operation indicated satisfactory performance at air supply pressures as low as 40 psia. A closed loop uncompensated frequency response of 9 cps was obtained under ambient conditions. Compensating networks are being added to increase the frequency response to 15 cps.

Analyses were made of the dynamic response characteristics of the nuclear instrumentation in the engine ground control system to provide basic information for reactor start up studies. It was indicated that no serious stability problems exist, and power can be increased from source level to 0.1 percent of full power with a step in command and an inverse period override.

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

~~SECRET RESTRICTED DATA~~

5876

~~ATOMIC ENERGY ACT OF 1954~~

Very promising results were obtained from the electronics irradiation test performed in August 1961 at General Dynamics/Fort Worth. The magnetic amplifier circuits incorporating General Electric ZJ225 diodes exhibited good radiation resistance. One circuit operated satisfactorily to a dose of  $2 \times 10^{15}$  nvt, a dose in excess of that expected during a typical mission. On the strength of results obtained from this first irradiation test, a set of second generation circuits and components was prepared for another irradiation test to be performed in January 1962. These second generation circuits employ ZJ225 diodes that have been specially prepared and individually selected. The diodes were subjected to screening tests (including preliminary low level gamma and neutron irradiation) to insure uniformity and maximum reliability. These circuits are expected to operate satisfactorily to integrated neutron dosages well beyond requirements for Pluto applications.

Ground test facility studies have been aimed at the establishment of facility performance and design criteria, the delineation of minimum facility requirements, and the assessment of the economies associated with various air supply systems. Facility performance criteria have been revised to account for changes in engine test planning and facility utilization. Present emphasis points to the use of the facility for testing of flight engines only, with runtimes based on simulation of maximum anticipated run time at full reactor power. Sustained full power operation is assumed to occur for a maximum of 90 minutes during the dash portion of the mission profile. This installed capability allows simulation of a complete mission trajectory in two separate test runs.

Facility cost estimates have been made for a variety of air storage schemes and run times. A cost of \$21.9 million is estimated for a minimal facility capable of simulating a Mach 3.0 sea level dash of 90-minute duration. This facility is based on the use of underground air storage, a minimum of exhaust handling equipment, continuous vitiated air heating, and the sharing of certain Tory IIC facilities.

Phase I of the Underground Air Storage Experiment was concluded with the completion of the core drilling program and submittal to the AEC of final drawings and specifications for the experimental chamber. The core drilling program confirmed the existence of suitable rock structure at a point approximately 8500 feet east-southeast of the Tory test point. Test chamber construction is scheduled to begin early in 1962.

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

DECLASSIFIED IN FULL

Authority: EO 13526

Chief, Records & Declass Div, WHS

Date: MAY 29 2015

Previous page was blank, therefore not filmed.



~~SECRET RESTRICTED DATA~~

RT 5876

~~ATOMIC ENERGY ACT OF 1954~~

### 3.0 PROPULSION SYSTEM DESIGN AND ANALYSIS

#### 3.1 TORY IIC DESIGN DATA

The Marquardt Model MA50-XCA propulsion system presently being considered for nuclear ramjet application utilizes a Tory IIC type reactor. Responsibility for Tory IIC reactor development and testing is vested in the Lawrence Radiation Laboratory (LRL), prime contractor for the Atomic Energy Commission.

Information relative to the Tory IIC configuration, performance, materials, etc., has been published by LRL in the Tory IIC Data Book (Reference 1). Data revisions are issued periodically by LRL and incorporated in propulsion system design and performance analyses.

Table 1 presents basic performance data for the Tory IIC reactor revised to 16 November 1961. It should be remembered that these data are preliminary in nature. Continuing optimization studies in combination with applicable experimental information will result ultimately in a firm reactor certification.

#### 3.2 PERFORMANCE ANALYSIS

##### 3.2.1 Propulsion System Performance

###### Status

The Model MA50-XCA propulsion system incorporates a variable geometry external-internal compression inlet, an S-shaped subsonic diffuser duct, the Tory IIC type reactor, and a fixed convergent-divergent exit nozzle. The design point Mach number is 2.8 at an altitude of 1,000 feet for the ANA Hot Day condition.

At the beginning of the year it was generally recognized that a propulsion system incorporating the Tory IIC reactor would provide insufficient thrust to propel a missile capable of performing the ADO No. 11 mission. In April, a coordination meeting was held at Aeronautical System Division (ASD), Dayton, Ohio, for the purpose of defining mutually acceptable areas of responsibility and investigation. At this meeting it was decided that the performance of a system utilizing Tory IIC reactor technology should be studied under what could be called Phase I. Tory IIC technology, including such items as reactor component materials and fabrication techniques, structural concepts, maximum design wall

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~





~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

TABLE 1  
 TORY HC PERFORMANCE

Minimum total reactor assembly flow area . . . . .	1060 sq in.
Fueled channel flow area . . . . .	848.7 sq in.
Tie rod peripheral channel flow area . . . . .	13.3 sq in.
Side reflector channel flow area . . . . .	34.5 sq in.
Standard tie rod flow area . . . . .	28.3 sq in.
Control tie rod flow area . . . . .	11.7 sq in.
Side support flow area . . . . .	123.4 sq in.
Fueled tube hole diameter . . . . .	0.227 sq in.
Fueled channel L/D ratio (length includes forward and aft reflectors and 1 1/2-inch thick base block) . . . . .	283
Missile condition simulated, Mach number at 1000 feet. . . . .	2.8
Total reactor flow rate . . . . .	1672 pps
Fueled tube flow rate (83.67%) . . . . .	1399 pps
Side reflector tube flow rate (1.48%) . . . . .	25 pps
Tie rod peripheral tube flow rate (1.14%) . . . . .	19 pps
Standard tie rod flow rate (4.67%) . . . . .	78 pps
Control tie rod flow rate (3.07%) . . . . .	51 pps
Side support annulus flow rate (5.97%) . . . . .	100 pps
Flow rate per fueled tube . . . . .	0.067 pps
Average exit stagnation temperature . . . . .	1987° F
Maximum fueled tube wall temperature . . . . .	2500° F
Maximum fueled tube internal temperature . . . . .	2564° F
Total reactor power . . . . .	510 Mw
Power per fueled channel . . . . .	23.88 Mw
Average fueled tube material power density* . . . . .	21.9 Mw/cu
Maximum fueled tube material power density . . . . .	26.19 Mw/c ft
Maximum volumetric power density* . . . . .	12.31 Mw/c ft
Fueled tube entrance Mach number . . . . .	0.215
Fueled tube exit Mach number . . . . .	0.457
Fueled tube entrance stagnation temperature . . . . .	946° F
Fueled tube exit stagnation temperature . . . . .	2157° F
Fueled tube entrance stagnation pressure . . . . .	322 psia
Fueled tube exit stagnation pressure** . . . . .	230 psia
Stagnation pressure drop across reactor . . . . .	92 psi
Expected reactor stagnation pressure loss . . . . .	7.2%
Entrance loss . . . . .	0.4%
Tube offset loss . . . . .	1.8%
Exit loss . . . . .	5.0%
Fueled tube maximum thermal stress . . . . .	15,200 psi

\* Based on active core volume

\*\* Not corrected for "Expected Reactor Stagnation Pressure Loss"

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~





~~SECRET RESTRICTED DATA~~

BT 5876

~~ATOMIC ENERGY ACT OF 1954~~

temperature, fuel element power density, and cooling airflows was to be preserved under Phase I. To account for the inadequate thrust level, the reactor diameter would be allowed to grow to meet the mission requirements. The aerothermodynamics contractor stated that the missile-propulsion system combination would be sized by about September 1961. Under Phase II, potential performance gains to be realized through improvement of Tory IIC technology were to be studied.

Phase I performance prediction of the propulsion system incorporating the Tory IIC type reactor was completed with the publication of the first three Performance Bulletins. Phase II is represented by Performance Bulletin No. 4, which is an integral part of this report.

#### Analytical Approach

Reactor neutronic, dimensional, and performance data have been taken wherever possible from the Tory IIC Data Book prepared by LRL. Marquardt IBM performance programs have incorporated this reactor information together with the inlet performance data of Figure 1 and the assumption of a one-dimensional exit nozzle flow with a 98 percent velocity coefficient. The procedure has been to airflow-optimize the propulsion system to provide a maximum thrust per unit reactor frontal area at the design point for a maximum reactor wall temperature of 2500°F. Side support cooling airflow rate, as specified by LRL, is collected at the exit of the pressure shell and passed through the nozzle coolant channels. The drag associated with the side support-nozzle combination has been included in the net jet thrust. Engine installation drag, composed of inlet supersonic spillage drag, inlet bleed drag, and engine bypass drag necessary for engine-inlet airflow matching, has been specified. By agreement, the airframe contractor will determine and account for the other installational drag items.

#### Performance Bulletin No. 1\*

Performance Bulletin No. 1 contains the initial performance analysis of the Model MA50-XCA propulsion system. In the course of the analysis it was necessary for Marquardt to generate input information on void fractions and equivalent flow diameters of the front grid and side support sections as well as nuclear heat generation rates in nonnuclear components. These data were not contained in the Tory IIC Data Book at that time. At the design point a net jet thrust coefficient of 0.195 was determined. The net jet thrust coefficient minus inlet bleed drag was found to be 0.173, or within 1.2 percent of the LRL value.

\*Reference 2.

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

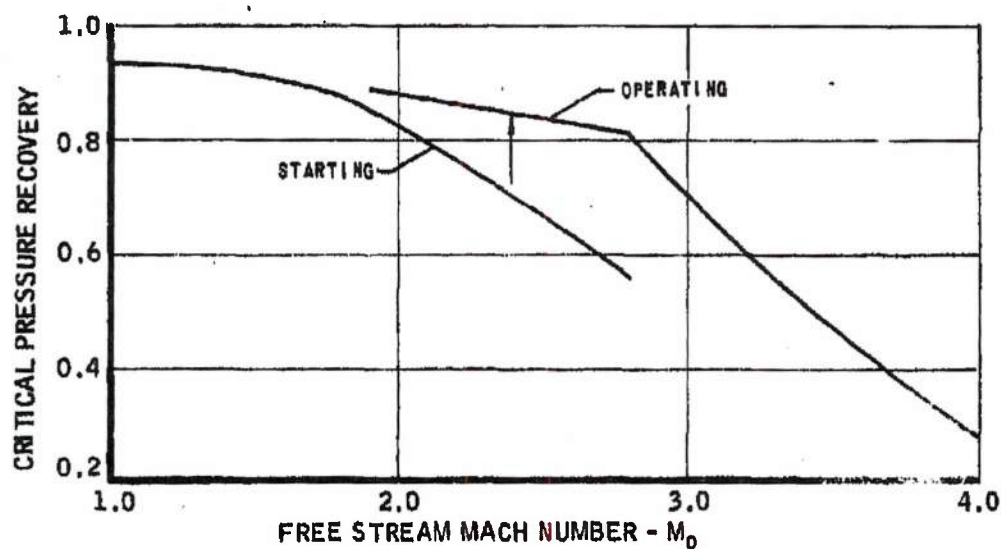
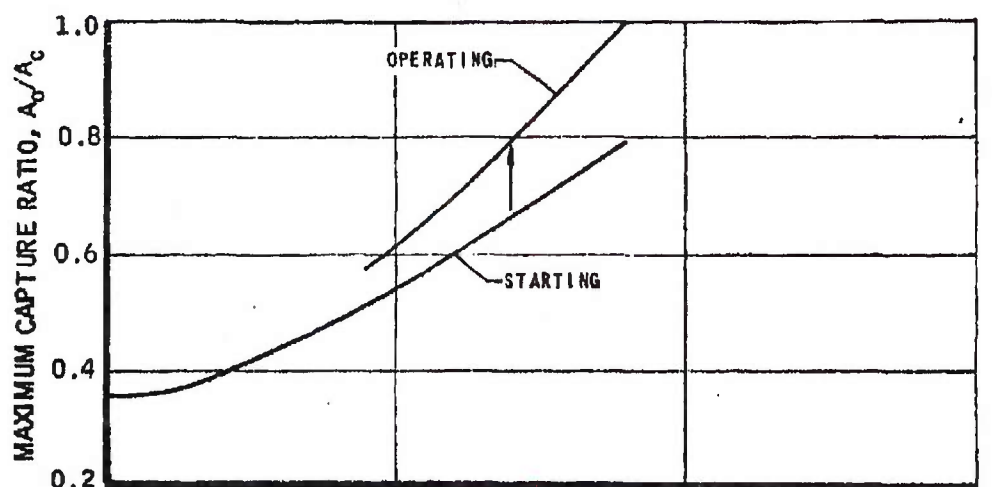
~~SECRET RESTRICTED DATA~~

THE *Marquardt*  
CORPORATION  
VAN NUYS, CALIFORNIA

REPORT 58

~~ATOMIC ENERGY ACT OF 1954~~

### ESTIMATED PERFORMANCE OF BASIC INLET FOR MA50-XCA ENGINE



DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~



~~SECRET RESTRICTED DATA~~

REF ID: A5876

~~ATOMIC ENERGY ACT OF 1954~~

Performance data on jet thrust coefficient, reactor thermal pressure recovery and airflow ratio, and installed drag were determined for a range of day conditions at an altitude of 1,000 feet and for the Standard Day condition at 30,000 feet. These data are included in Figures 2 through 9. The effect of inlet pressure recovery on the net jet thrust coefficient was established for Standard Day conditions and is presented in Figures 10 and 11. Near the design point, a 1.7 percent change in thrust coefficient per percent change in pressure recovery is indicated for the Model MA50-XCA propulsion system.

Included in the bulletins was a brief study of the performance gains to be realized by raising the reactor wall temperature above the present 2500°F design point. Two analyses were conducted, one in which only the reactor temperature was changed and the other in which the inlet and exit were resized for the higher temperature. In Figure 12, the maximum reactor wall temperature increased 200°F while maintaining the Model MA50-XCA sized inlet and exit areas. In Figure 13 the inlet and exit were resized for the higher temperature. These data indicate a 6.5 percent change in thrust coefficient per 100°F change in reactor wall temperature. These studies, while bordering on Phase II, were meant only to indicate performance trends. LRL has not as yet indicated occurrence in temperatures greater than 2500°F.

#### Performance Bulletin No. 2\*

With receipt of the revised Tory IIC Data Book, input information became available on side support, void fraction, and equivalent flow hydraulic diameter as well as nuclear heat generation in nonnuclear components. Using this new information, the performance predictions for the Model MA50-XCA propulsion system were revised and published in Performance Bulletin No. 2. The design point aerodynamic performance characteristics are compared in Table 2. The first column indicates the performance of the Model MA50-XCA system as determined in Performance Bulletin No. 1. The second column contains data from Performance Bulletin No. 2. It can be seen that the inputs from the revised Tory IIC Data Book resulted in relatively small changes. The net jet thrust coefficient increased from 0.195 to 0.200. This change in performance was due principally to a revision of the momentum drag losses in the side support-nozzle system.

At the request of the aerothermodynamics contractor, the second bulletin extended the altitude performance data for the Standard Day condition. These data, presented in Figures 14 and 15, are based on the same assumptions as those presented in Performance Bulletin No. 1. At the request of the aerothermodynamics contractor, the effect of scaling the Tory IIC reactor to larger diameters

\*Reference 3

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

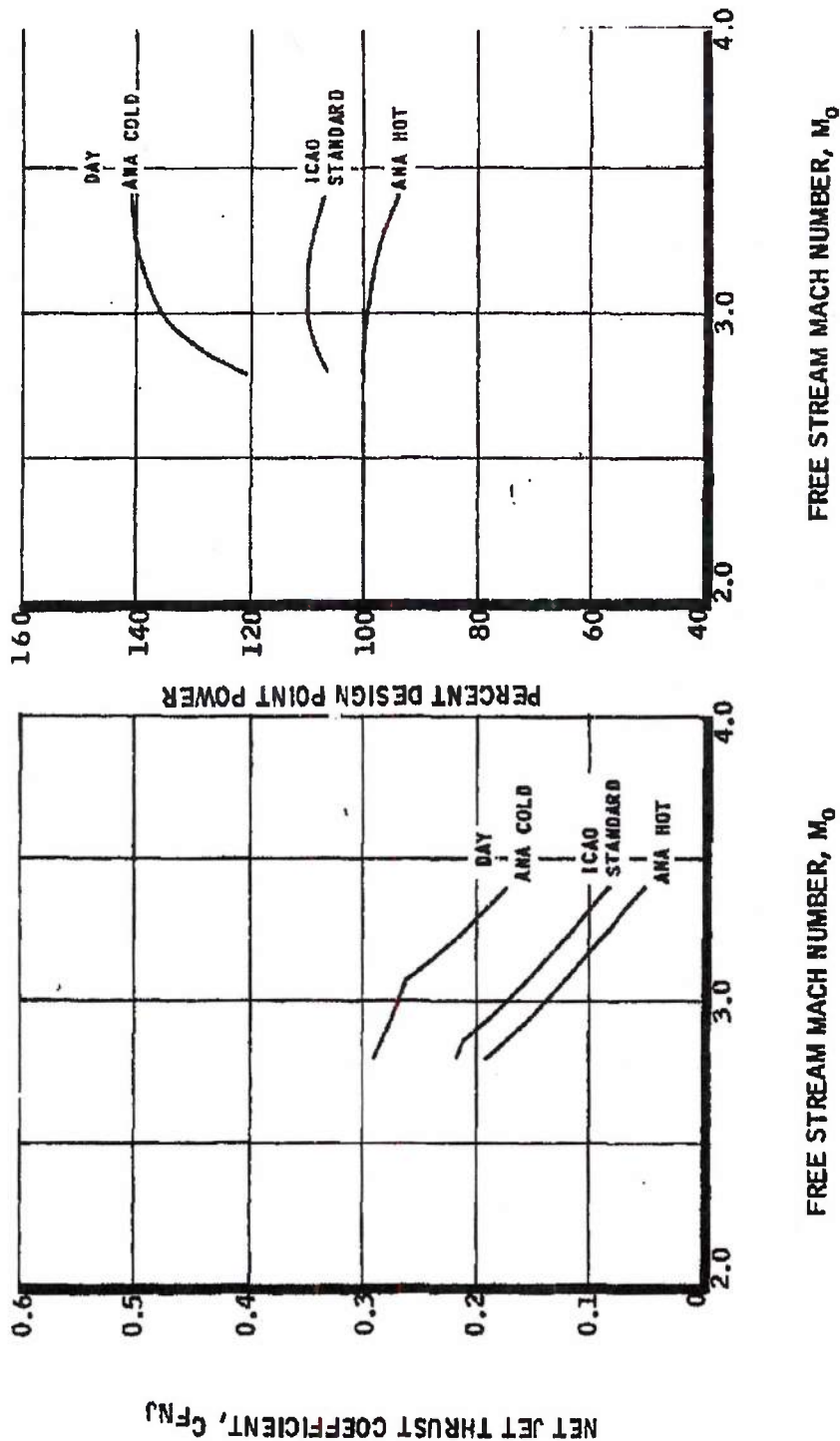
~~SECRET RESTRICTED DATA~~

ATOMIC ENERGY ACT OF 1954

ESTIMATED THRUST COEFFICIENT OF MA50-XCA RAMJET

AT ALTITUDE OF 1000 FEET

MAXIMUM WALL TEMPERATURE = 2960 °R



FREE STREAM MACH NUMBER,  $M_0$

FREE STREAM MACH NUMBER,  $M_0$

~~SECRET RESTRICTED DATA~~

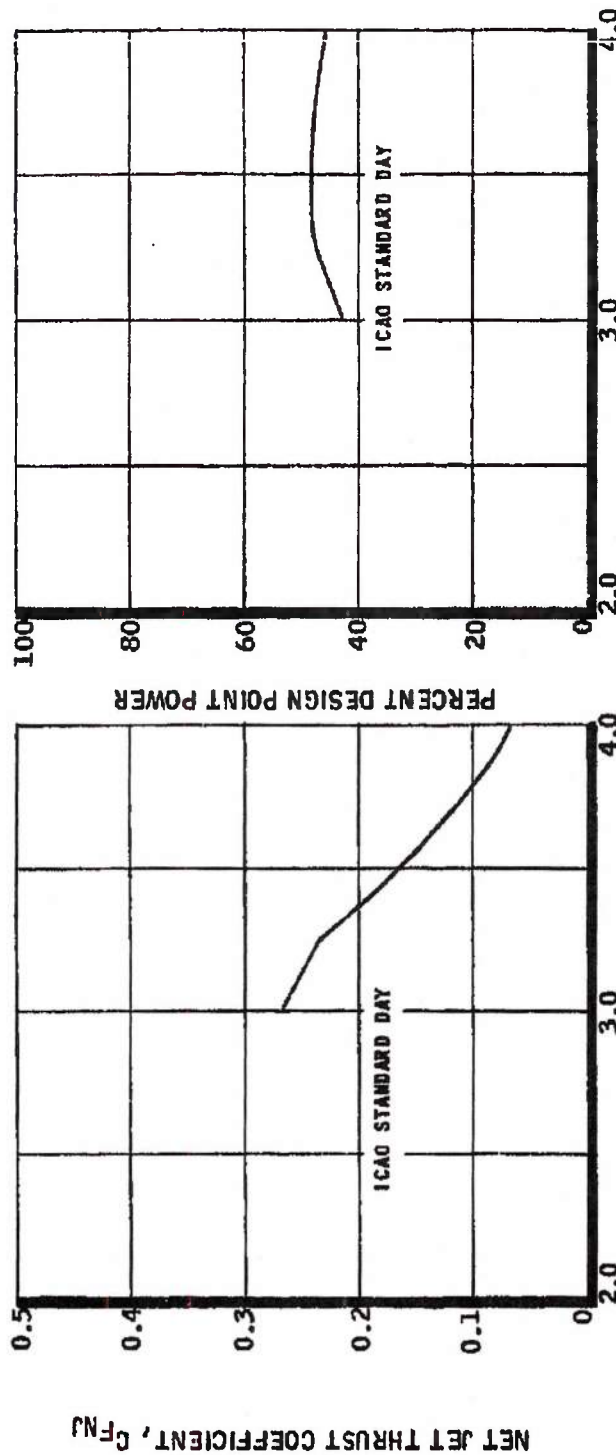


~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

ESTIMATED THRUST COEFFICIENT OF MA50-XCA RAMJET  
AT ALTITUDE OF 30,000 FEET

MAXIMUM WALL TEMPERATURE = 2960°R



MAC 603

~~SECRET RESTRICTED DATA~~

FIGURE 3

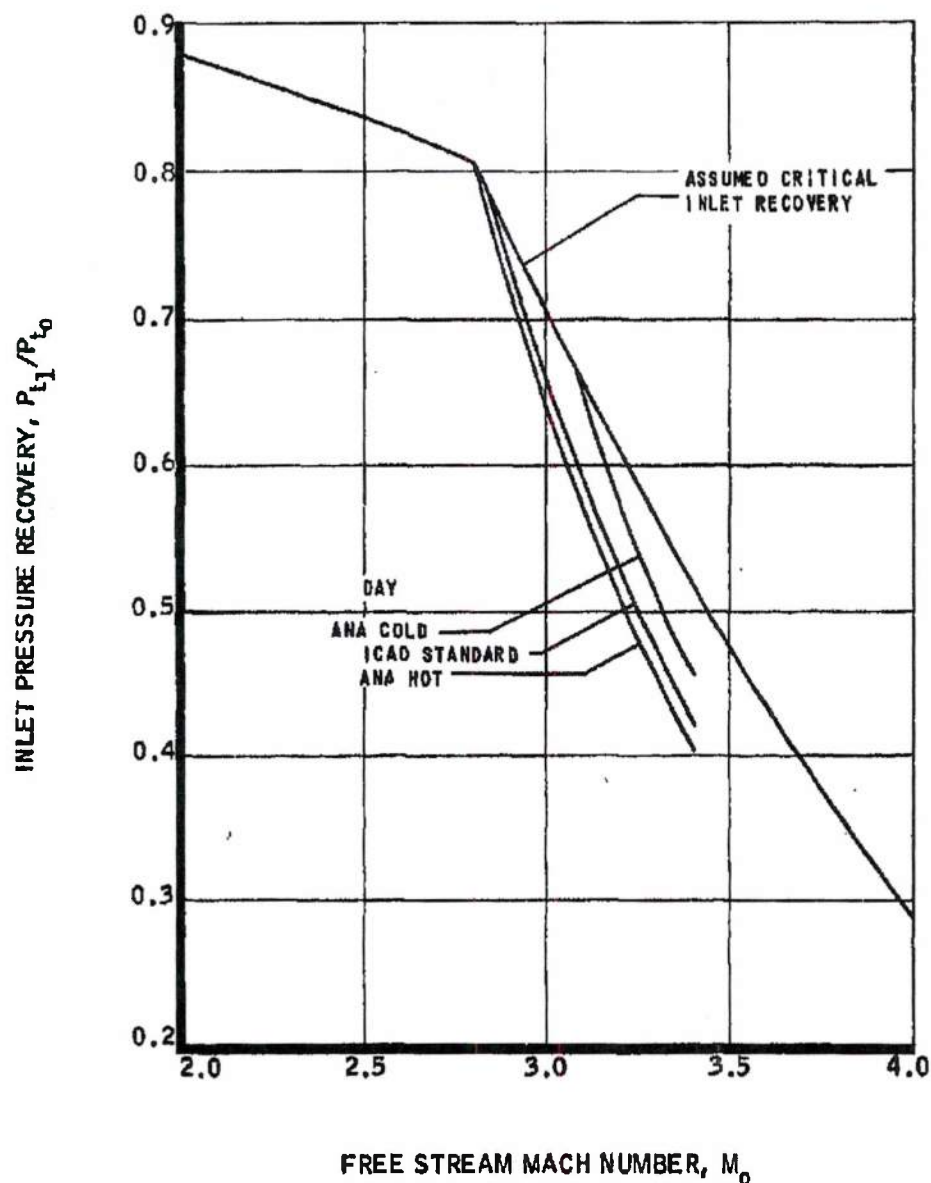
~~SECRET RESTRICTED DATA~~

*The* **Marquardt**  
CORPORATION  
VAN NUYS, CALIFORNIA

REPORT 58

~~ATOMIC ENERGY ACT OF 1954~~

INLET PRESSURE RECOVERY OF MA50-XCA RAMJET  
AT ALTITUDE OF 1000 FEET  
MAXIMUM WALL TEMPERATURE = 2960°R



DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

N22E369 ~~ATOMIC ENERGY ACT OF 1954~~ -14-

FIGUR 4

~~SECRET RESTRICTED DATA~~

THE *Marquardt*  
CORPORATION  
VAN NUYS, CALIFORNIA

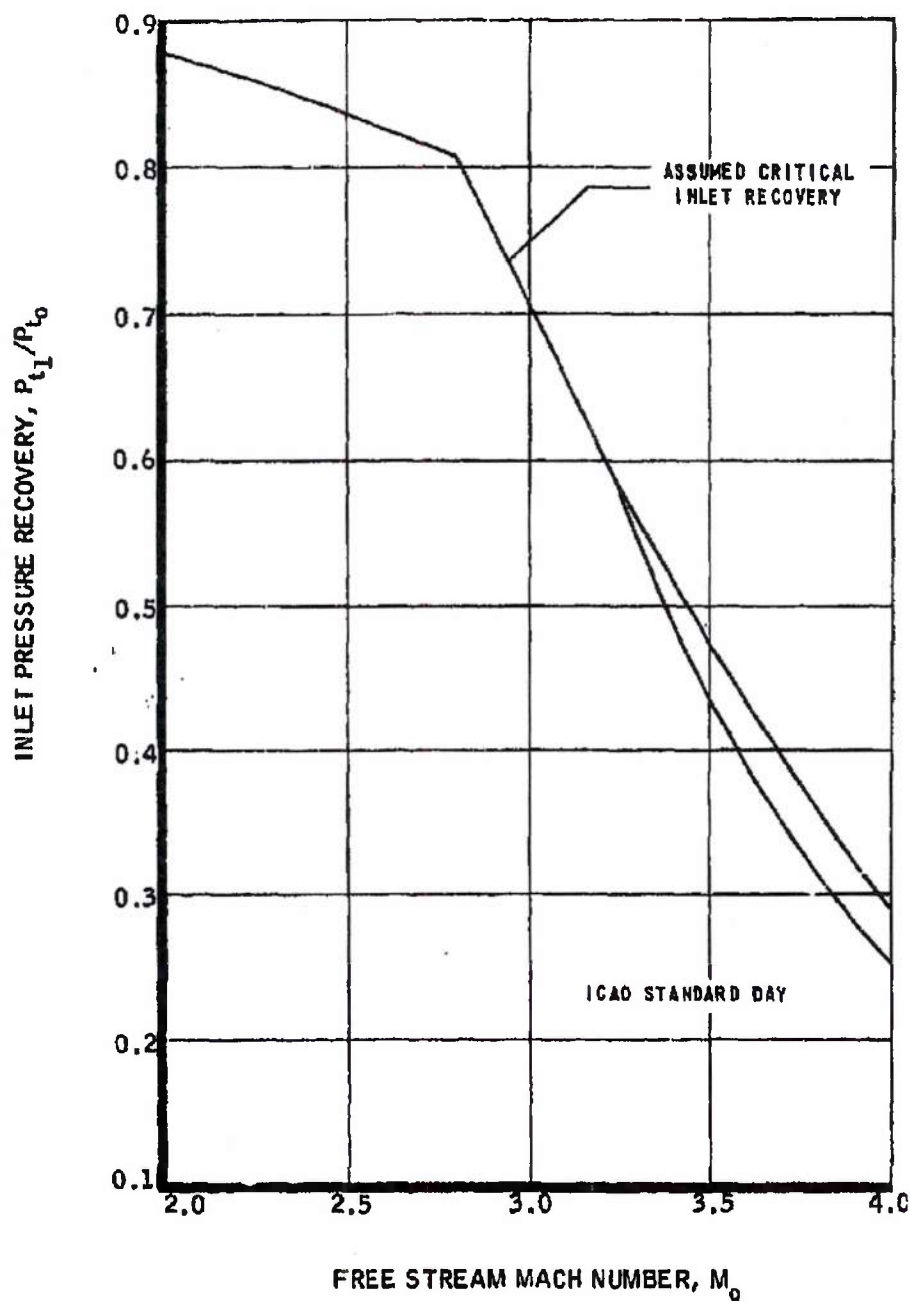
REF ID: A5876

ATOMIC ENERGY ACT OF 1954

### INLET PRESSURE RECOVERY OF MA50-XCA RAMJET AT

ALTITUDE OF 30,000 FEET

MAXIMUM WALL TEMPERATURE = 2960°R



SAC AGO

~~SECRET RESTRICTED DATA~~

N22E370 ATOMIC ENERGY ACT OF 1954 - 15 -

FIGURE 5

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

SECRET RESTRICTED DATA

*Marquardt*  
VAN NUYS, CALIFORNIA

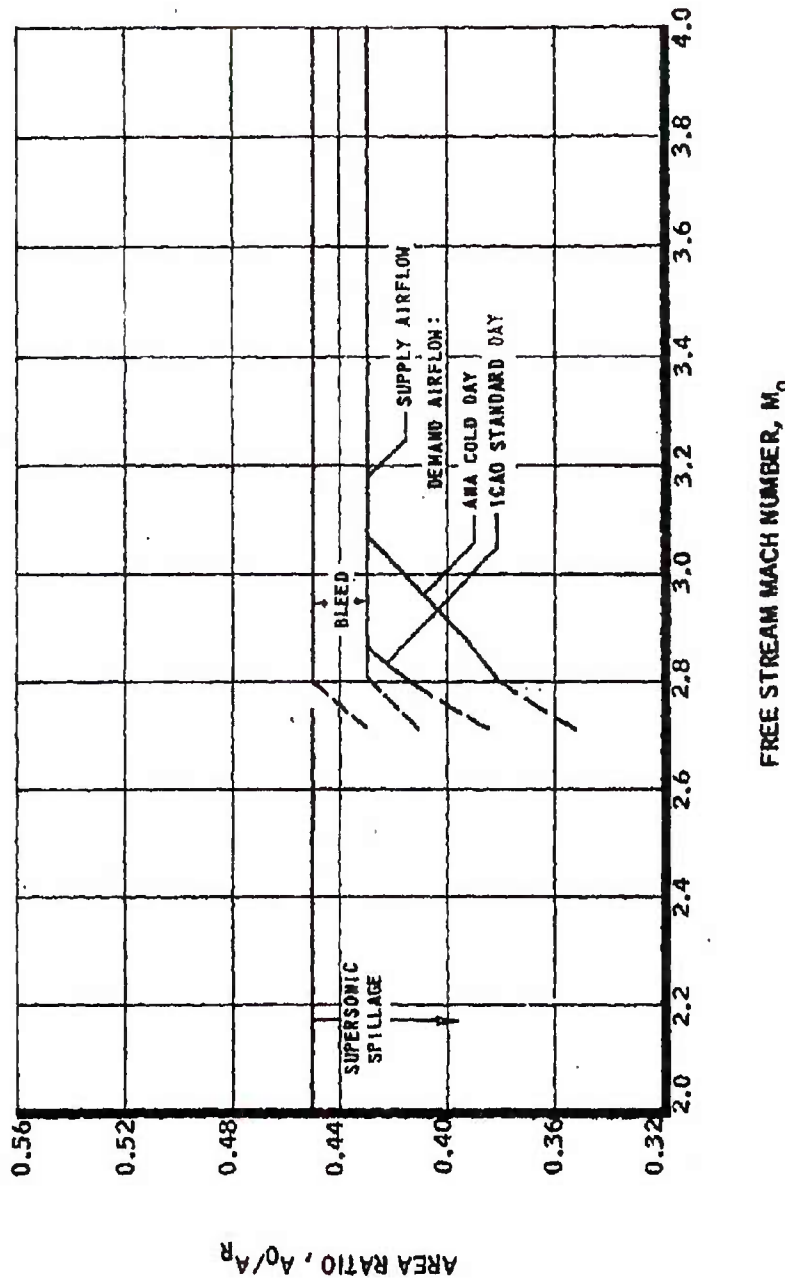
REPORT 5876

ATOMIC ENERGY ACT OF 1954

FREE STREAM CAPTURE AREA RATIO OF MA50-XCA RAMJET

AT ALTITUDE OF 1000 FEET

MAXIMUM WALL TEMPERATURE = 2960° R



MAC 4437

SECRET RESTRICTED DATA

N22E371 ATOMIC ENERGY ACT OF 1954 -16-

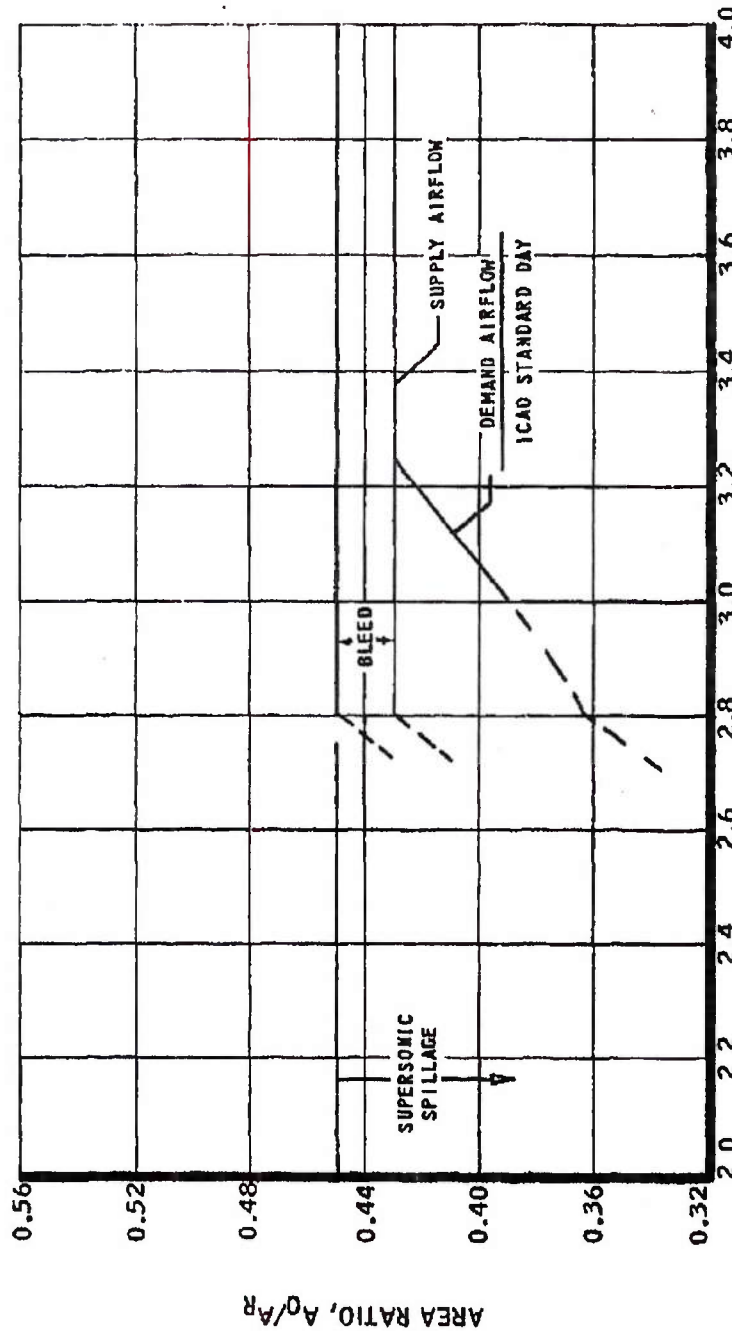
FIGURE 6  
DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHIS  
Date: MAY 29 2015



~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

FREE STREAM CAPTURE AREA RATIO OF MA50-XCA  
RAMJET AT ALTITUDE OF 30,000 FEET  
MAXIMUM WALL TEMPERATURE = 2960 °R



FREE STREAM MACH NUMBER,  $M_0$

~~SECRET RESTRICTED DATA~~

N22E372 ~~ATOMIC ENERGY ACT OF 1954~~ - 17 -

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WIS  
Date: MAY 29 2015

FIGURE 7

~~SECRET RESTRICTED DATA~~

THE *Marquardt*  
CORPORATION  
VAN NUYS, CALIFORNIA

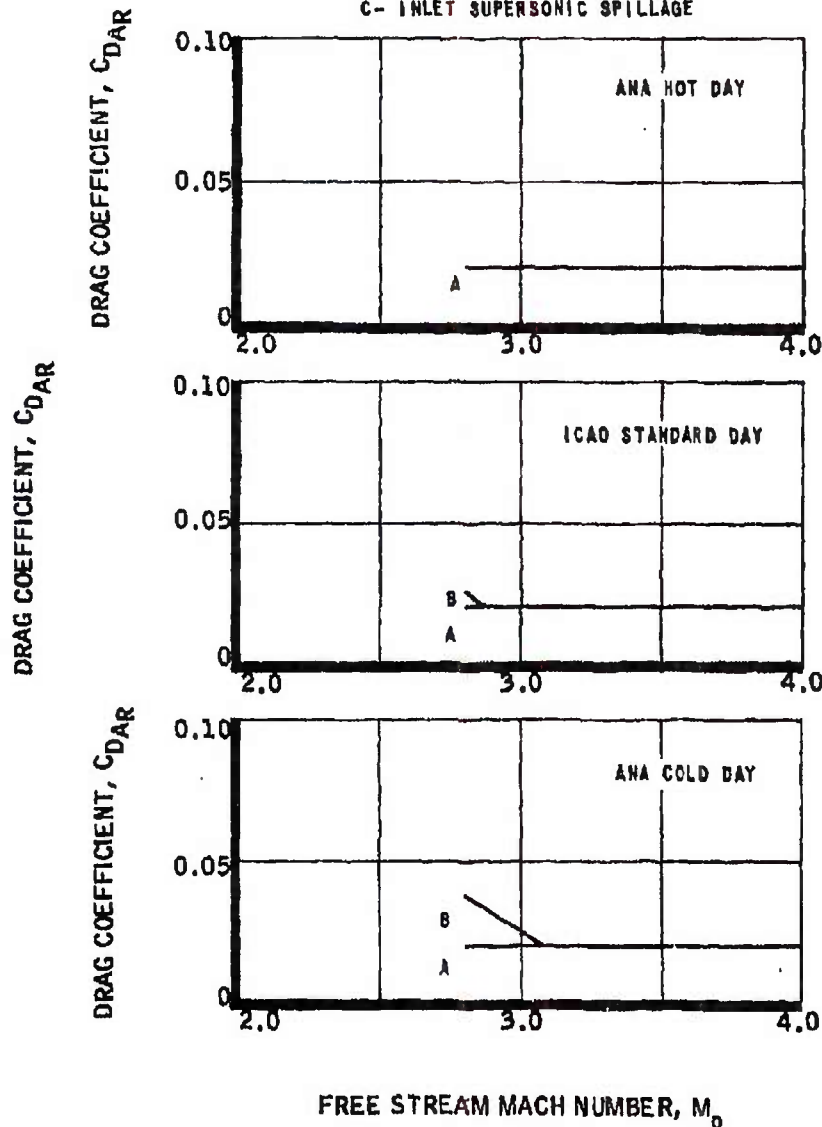
REPORT 581

~~ATOMIC ENERGY ACT OF 1954~~

DRAG OF MA50-XCA RAMJET ENGINE INSTALLATION  
AT ALTITUDE OF 1000 FEET

MAXIMUM WALL TEMPERATURE = 2960°R  
DRAG COMPONENTS

- A- INLET BLEED
- B- BYPASS
- C- INLET SUPERSONIC SPILLAGE



~~SECRET RESTRICTED DATA~~

N22E377

~~ATOMIC ENERGY ACT OF 1954~~ - 18 -

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WIIS  
Date: MAY 29 2015

FIGUR 8

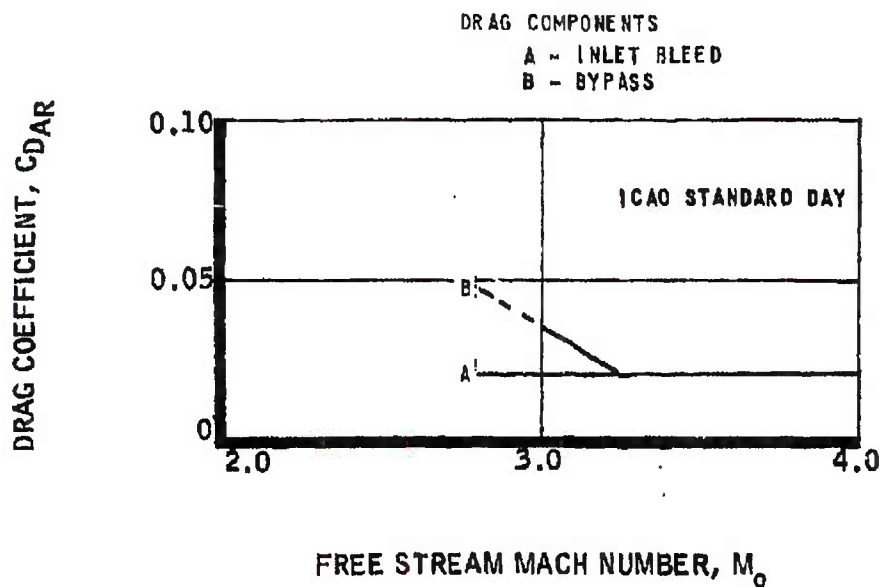
~~SECRET RESTRICTED DATA~~

DRT 5876

ATOMIC ENERGY ACT OF 1954

DRAG OF MA50-XCA RAMJET ENGINE INSTALLATIO AT  
ALTITUDE OF 30,000 FEET

MAXIMUM WALL TEMPERATURE = 2960°R



DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WIS  
Date: MAY 29 2015

MAC 4023

~~SECRET RESTRICTED DATA~~

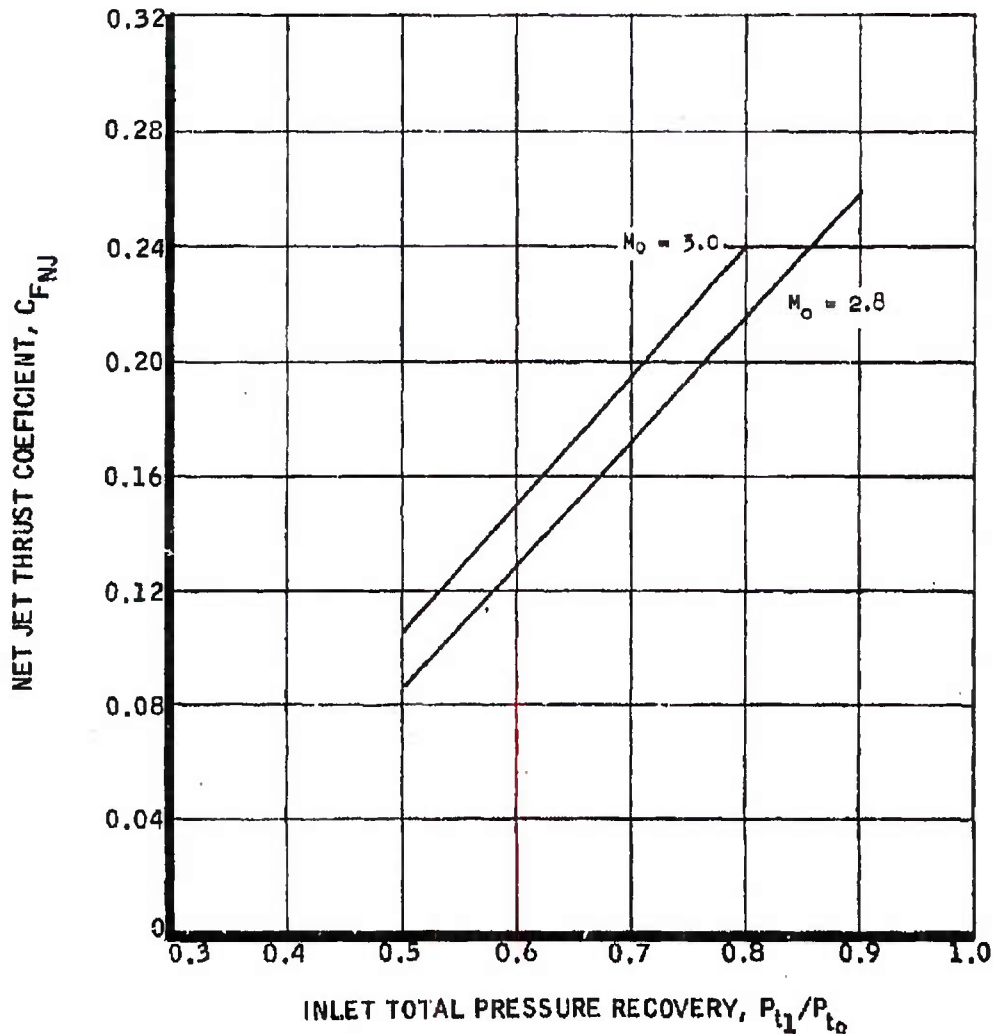
N22E378 ~~ATOMIC ENERGY ACT OF 1954~~ -19-

FIGURE 9

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

EFFECT OF INLET PRESSURE RECOVERY OF MA50-XCA RAMJET  
AT ALTITUDE OF 1000 FEET  
MAXIMUM WALL TEMPERATURE = 2960 °R



DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~



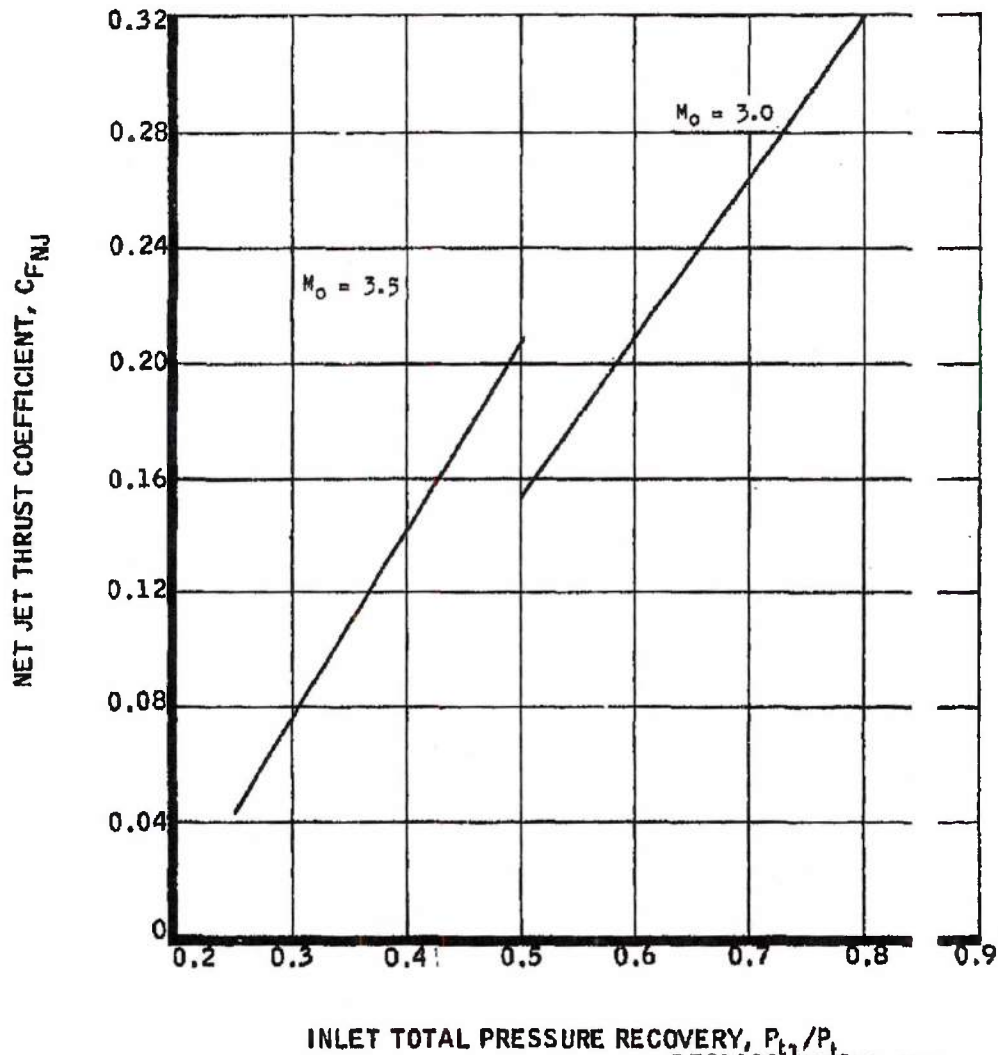
~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

# EFFECT OF INLET PRESSURE RECOVERY OF MA50-XCA RA JET

AT ALTITUDE OF 30,000 FEET

MAXIMUM WALL TEMPERATURE = 2960°R



DECLASSIFIED IN FULL  
 Authority: EO 13526  
 Chief, Records & Declass Div, WHS  
 Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

N22E376 ~~ATOMIC ENERGY ACT OF 1954~~ -21-

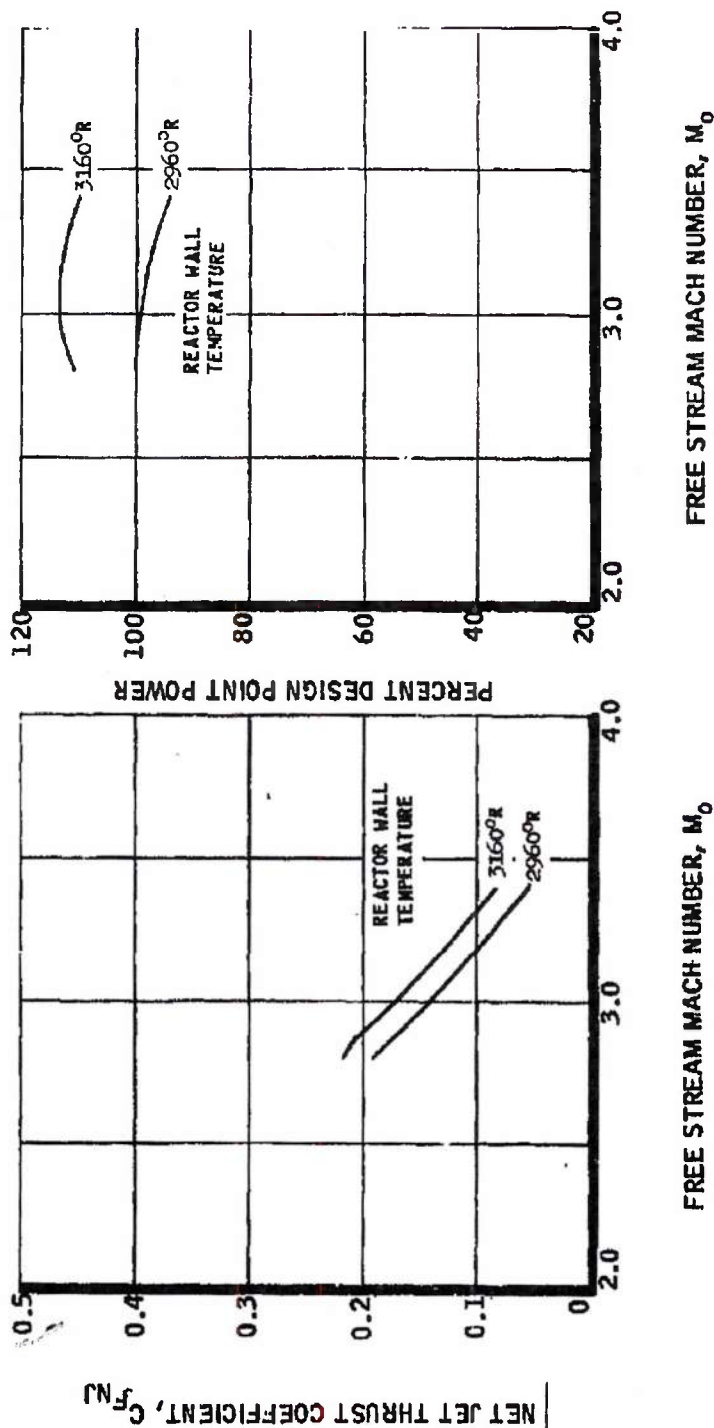
FIGURE 11

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

ESTIMATED THRUST COEFFICIENT OF MA50-XCA RAMJET

ALTITUDE = 1,000 FEET  
 ANA HOT DAY



~~SECRET RESTRICTED DATA~~

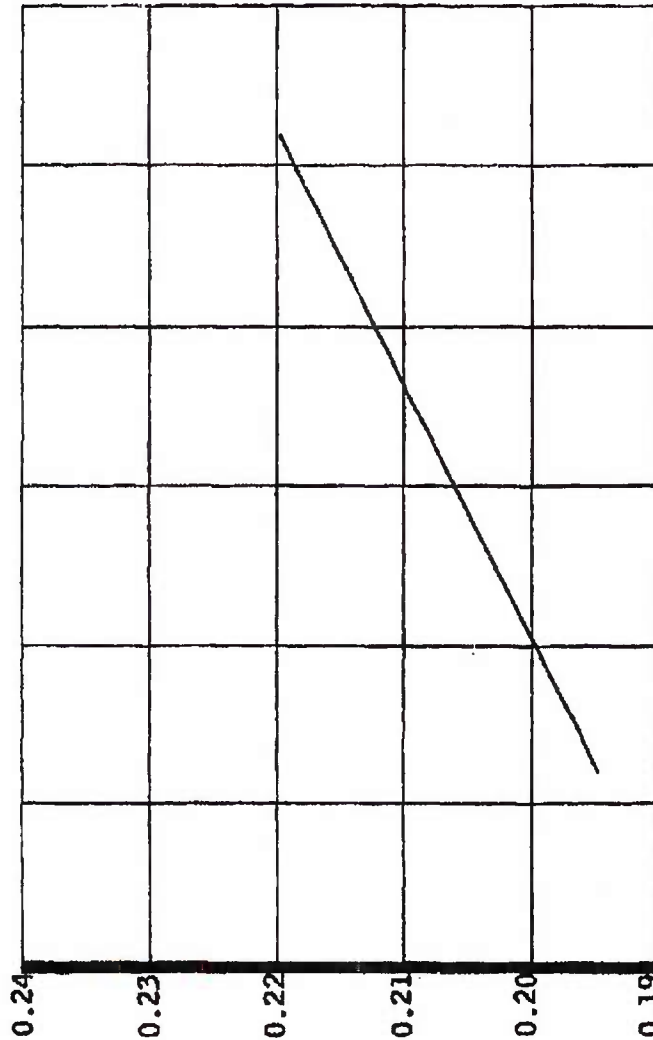
~~SECRET RESTRICTED DATA~~

5876

~~ATOMIC ENERGY ACT OF 1954~~

# EFFECT OF WALL TEMPERATURE ON NET JET THRUST COEFFICIENT AT DESIGN POINT

NOTE: A. OPTIMIZED INLET AND EXIT  
B. TORY IIC - I REACTOR SCALED TO 3160°R. (DIFFERENTIAL NEUTRONIC  
EFFECTS BETWEEN  $T_w = 2960^{\circ}R$  TO  $T_w = 3160^{\circ}R$  NOT INCLUDED)



WALL TEMPERATURE  $T_{wall}$  ~ degrees R

NET JET THRUST COEFFICIENT,  $C_{FN}$

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

DECLASSIFIED IN FULL

Authority: EO 13526

Chief, Records & Declass Div, WHS

Date: MAY 29 2015



REPORT 58

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

TABLE 2

COMPARISON OF AEROTHERMODYNAMIC PERFORMANCE  
CHARACTERISTICS AT THE DESIGN POINT

(Mach 2.8; ANA Hot Day Temperature; Altitude, 1000 feet)

Parameter	MA50-XCA	MA50-XCA (Revised)	MA50-XCA (Isothermal)
Reactor Air Flow, $W_a$ , lb/sec	1,577	1,577	1,53
Side Support Cooling Air Flow, $W_{ac}$ , lb/sec	113	113	113
Inlet Total Pressure, $P_{t0}$ , psia	393	393	393
Inlet Total Temperature, $T_{t0}$ , °R	1,402	1,402	1,40
Inlet Recovery, $P_{t1}/P_{t0}$	0.807	0.807	0.80
Core Inlet Mach Number, $M_3$	0.23	0.23	0.2
Core Tube Diameter, ft	0.0189	0.0189	0.018
Maximum Core Wall Temperature, $T_w$ , °R	2,960	2,960	2,96
Total Reactor Power, $Q$ , Mw	518	518	568
Reactor Ceramic Average Void Fraction	0.416	0.416	0.41
Reactor Exit (mixed) Total Temper- ature, $T_{t4}$ , °R	2,522	2,520	2,65
Reactor Pressure Recovery, $P_{t4}/P_{t1}$	0.678	0.678	0.671
Reactor Diameter, $D_R$ , in.	57	57	57
Reactor Length, $L_R$ , in.	62.7	62.7	62.7
Reactor Area, $A_R$ , ft <sup>2</sup>	17.72	17.72	17.72
Nozzle Throat Area, $A_5$ , ft <sup>2</sup>	4.94	4.94	4.97
Nozzle Exit Area, $A_6$ , ft <sup>2</sup>	12.74	12.74	12.86
Cowl Area, $A_c$ , ft <sup>2</sup>	7.97	7.97	7.78
Exhaust Nozzle Velocity Coef- ficient, $C_v$	0.98	0.98	0.98
Thrust Coefficient, $C_{FAR}$ (Full Expansion)	0.195	0.200	0.221
Thrust, $F$ , (Full Expansion), lb	38,640	39,700	43,860

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~



~~SECRET RESTRICTED DATA~~

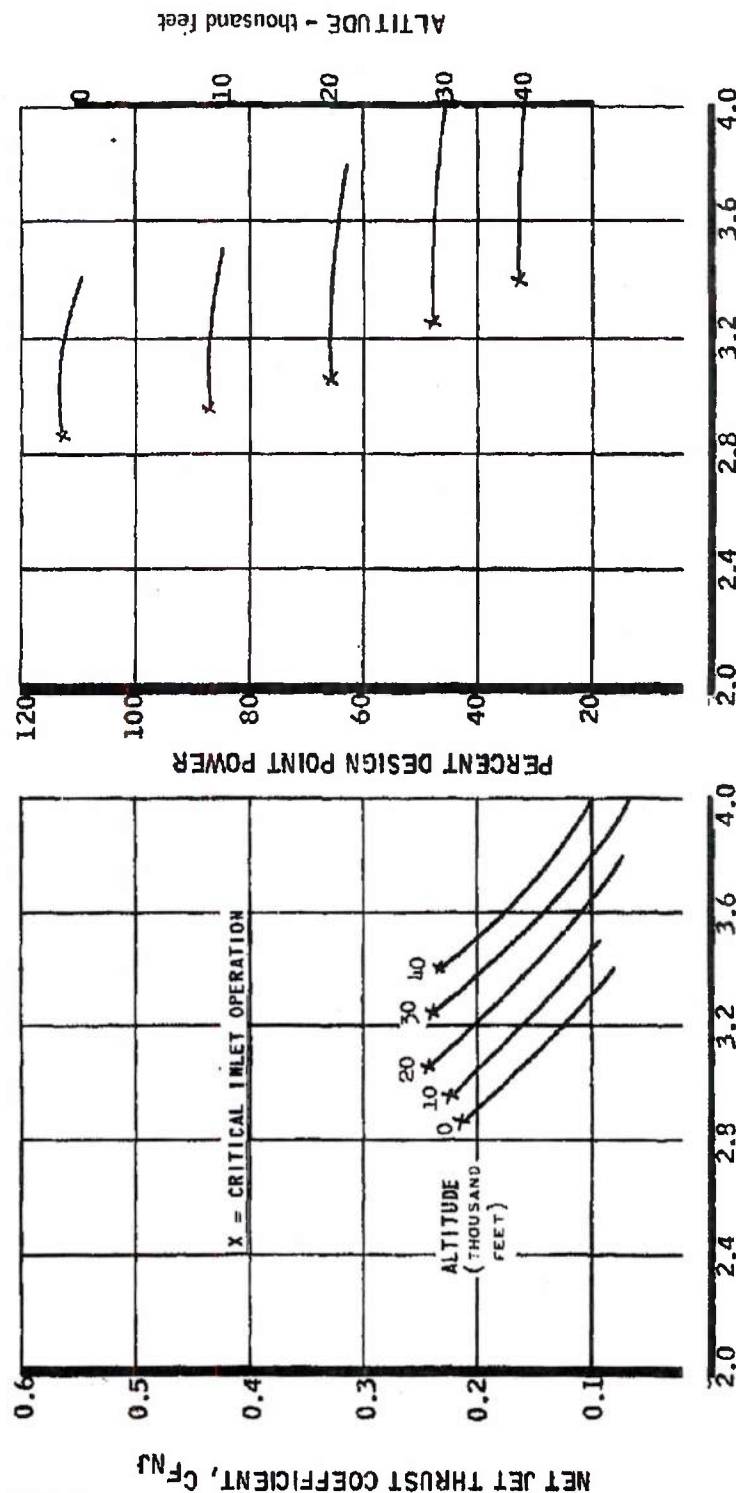
~~ATOMIC ENERGY ACT OF 1954~~

MAC 6673

# ESTIMATED THRUST COEFFICIENT

ICAO STANDARD DAY

$T_{H_{MAX}} = 2960^{\circ}R$



FREE STREAM MACH NUMBER,  $M_0$

~~SECRET RESTRICTED DATA~~

~~SECRET RESTRICTED DATA~~

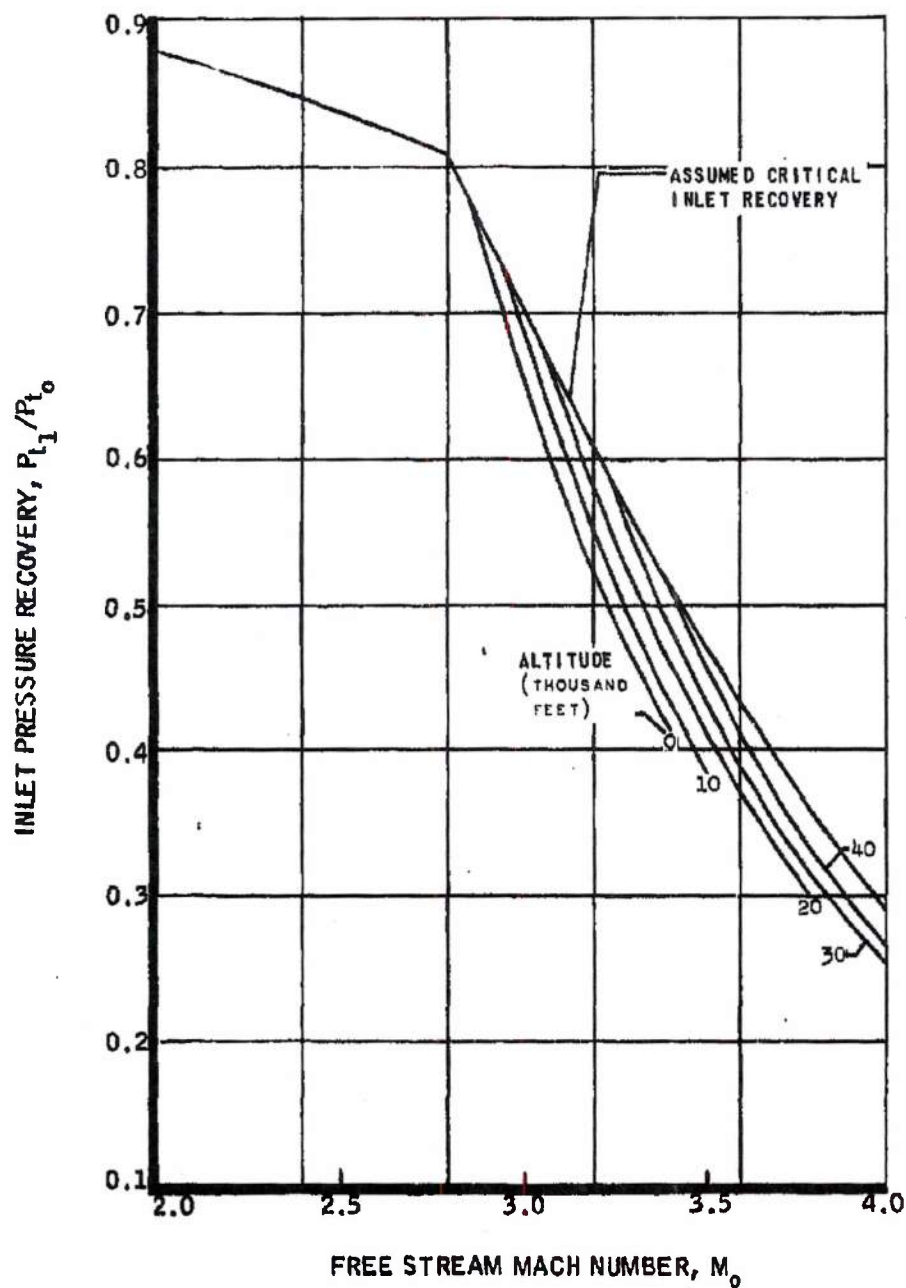
*The Marquardt Corporation*  
VAN NUYS, CALIFORNIA

REPORT E 76

~~ATOMIC ENERGY ACT OF 1954~~

### INLET PRESSURE RECOVERY

ICAO STANDARD DAY  
 $T_{W \text{ MAX.}} = 2960^{\circ}\text{R}$



~~SECRET RESTRICTED DATA~~

N22E382

~~ATOMIC ENERGY ACT OF 1954~~

-26-

DECLASSIFIED IN FULL FIGURE 15

Authority: EO 13526

Chief, Records & Declass Div, WHS

Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

ORI 5876

~~ATOMIC ENERGY ACT OF 1954~~

was also presented. This information, however, was found to be in error and was subsequently corrected in Performance Bulletin No. 3.

The final item presented in Performance Bulletin No. 2 was a study of the potential performance gains associated with a 2500°F isothermal wall in the Tory IIC reactor. Results of the study, based on the Model MA50-XA system geometry, are given in the third column of Table 2. A potential thrust gain of 10 percent is indicated. Achieving this performance would necessitate a 65 percent increase in the maximum power density in the core. LRL has indicated a desire not to increase power density until problems relating to fuel element thermal stress are more clearly defined. Additional study of the aerothermodynamics of the isothermal core indicated that a large weight reduction could be achieved without incurring a performance penalty by reducing the core length 9 percent.

#### Performance Bulletin No. 3\*

The reactor diameter scaling curve presented in Performance Bulletin No. 2 was revised, and the corrected data were given to the aerothermodynamics contractor. This information permitted the aerothermodynamics contractor to perform a first iteration on the reactor diameter necessary to satisfy the performance requirements of the ADO No. 11 mission. This diameter, mutually agreed upon by LRL, Marquardt, and the aerothermodynamics contractor, was set at 63 inches as compared to 57 inches for the basic Tory IIC reactor. This change in reactor diameter, combined with other modifications, resulted in a propulsion system sufficiently different from the Model MA50-XCA to warrant a separate identification. Accordingly, this system has been designated as the Model MA50-XDA. The size scaling curve is presented in Figure . The following assumptions were made in deriving this curve. The curve represents propulsion systems optimized for airflow to yield maximum thrust coefficient. The core power profile and the nuclear heat generation rates in nonnuclear components were considered to be independent of core diameter. Reflector thickness and tube geometries for all components were unchanged. The number of tie tubes and the projected frontal area of fueled core were increased as the square of the ceramic diameter. The unfueled region about each tie rod and the number of control rods were unchanged. The side support gap was maintained at 1.56 inches. In addition to the increased diameter, the core was reduced in length from 62.7 to 54.6 inches. The maximum wall temperature and reactor power density remained at the Tory IIC values. LRL has indicated concurrence in the above-noted changes to the basic Tory IIC reactor.

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

\* Reference 4

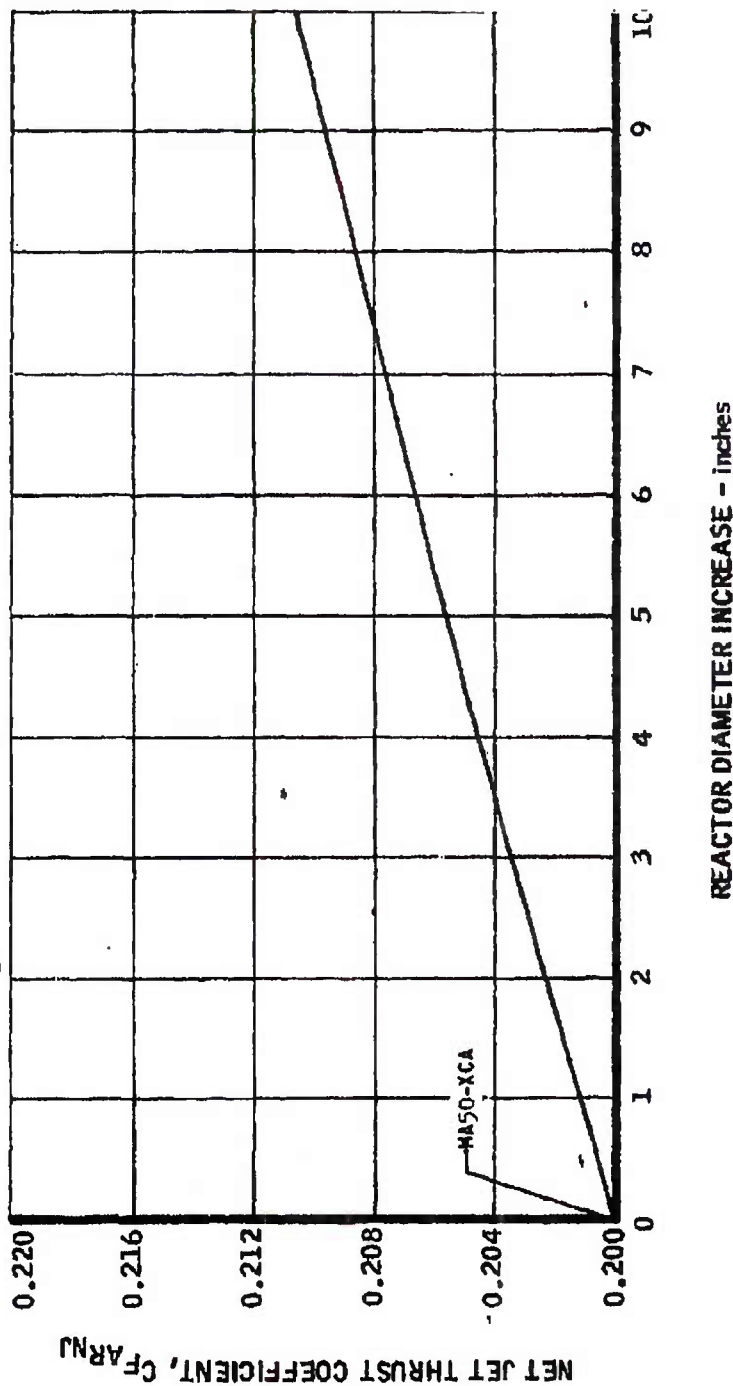
~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

EFFECT OF REACTOR DIAMETER INCREASE ON NET JET THRUST COEFFICIENT  
 (ERRATA SHEET FOR FIGURE 5 OF PERFORMANCE BULLETIN NO. 2)  
 (TORY 11C REACTOR LENGTH)



MAC 463

~~SECRET RESTRICTED DATA~~

N22E623 ~~ATOMIC ENERGY ACT OF 1954~~





~~SECRET RESTRICTED DATA~~

~~VAN NUYS, CALIFORNIA~~

REPORT 5876

~~ATOMIC ENERGY ACT OF 1954~~

The design point aerothermodynamic properties of the Model MA50-XDA propulsion system are presented in Table 3. The thrust coefficient has increased to 0.207, or 3-1/2 percent above the basic Model MA50-XCA thrust coefficient. This thrust gain was achieved in spite of an allowance of 2.2 inches for side support spring area gaps as compared to the 1.56-inch gap allowed for the Model MA50-XCA. The effect of the side support gap allowance may be noted by comparing Figure 17 to Figure 16. Figure 17 presents the revised scaling curve assuming a variable gap thickness with increased reactor diameter. It will be noted that this curve is much flatter than that presented in Figure 16 wherein the gap was maintained at 1.56 inches. A comparison of these two figures also indicates that a 3 percent thrust gain was achieved simply by shortening the Model MA50-XCA system as previously discussed. It is believed that the reactor scaling relationships utilizing the variable side support gap (Figure 17) is the more realistic of the two methods and will be utilized in all future analyses.

Net jet thrust, reactor thermal power, inlet pressure recovery and air-flow ratio, and installed drag were determined for altitudes of 1,000 and 30,000 feet and are presented in Figures 18 through 24 for the Model MA50-XDA system.

#### Performance Bulletin No. 4

With publication of the first three Performance Bulletins, Phase I of the performance work utilizing Tory IIC technology was concluded. Performance Bulletin No. 4, included as Section 3.3 of this report, represents initial Phase II performance studies, which are predicated on advancements in Tory IIC technology. The advances considered are as follows:

(1) A modification in the core power profile. By modifying the core power profile, thrust performance can be improved without exceeding the Tory IIC design limits of 15,000-psi elastic thermal stress and 2500°F maximum wall temperature. There follows an explanation of this improvement in thrust performance. With the present Tory IIC power profile, the 15,000-psi thermal stress limit is achieved at one location near the center of the core. At positions closer to the front of the core, the thermal stress falls off to lower values because of increased thermal conductivity through the fuel element at the lower temperatures. Similarly, at the rear of the reactor the wall temperature is less than the 2500°F limit. Figure 25 presents a comparison of relative power curves for the isothermal wall reactor, the Tory IIC reactor, and the revised profile for the Tory IIC, which more nearly fits the limiting conditions on elastic thermal stress.

MAC AGS

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

~~SECRET RESTRICTED DATA~~

REPORT 58

~~ATOMIC ENERGY ACT OF 1954~~

TABLE 3

MA50-XDA AEROTHERMODYNAMIC PERFORMANCE  
CHARACTERISTICS AT THE DESIGN POINT

(Mach 2.8; ANA Hot Day Temperature; Altitude, 1000 feet)

Parameter	MA50-XDA
Reactor Air Flow, $W_a$ , pps	2,012
Side Support Cooling Air Flow, $W_{ac}$ , pps	120
Inlet Total Pressure, $P_{t0}$ , psia	393
Inlet Total Temperature, $T_{t0}$ , °R	1,402
Inlet Recovery, $P_t/P_{t0}$	0.807
Core Inlet Mach Number, $M_3$	0.235
Core Tube Diameter, ft	0.0189
Maximum Core Wall Temperature, $T_w$ , °R	2,960
Total Reactor Power, $Q$ , Mw	654
Reactor Ceramic Average Void Fraction	0.421
Reactor Exit (Mixed) Total Temperature, $T_{th}$ , °R	2,510
Reactor Pressure Recovery, $P_{th}^i/P_{t1}$	0.683
Reactor Diameter, $D_R$ , in.	63
Reactor Length, $L_R$ , in.	54.6
Reactor Area, $A_R$ , sq ft	21.63
Nozzle Throat Area, $A_5$ , sq ft	6.2
Nozzle Exit Area, $A_6$ , sq ft	16.09
Cowl Area, $A_c$ , sq ft	10.05
Exhaust Nozzle Velocity Coefficient, $C_v$	0.98
Thrust Coefficient, $C_{FAR}$ , (Full expansion)	0.207
Thrust, $F$ , (Full expansion), lbs	50,200

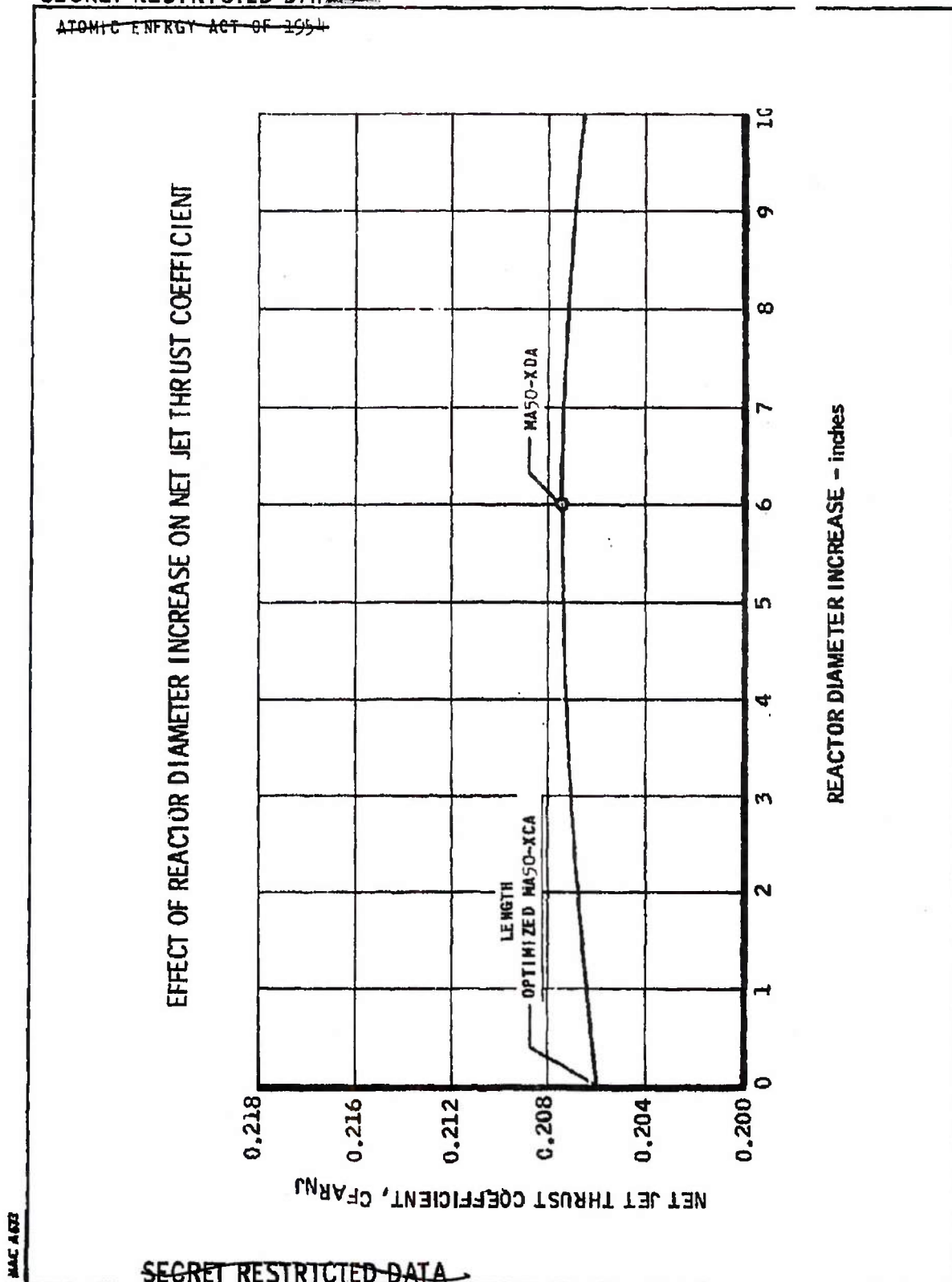
DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

~~SECRET RESTRICTED DATA~~

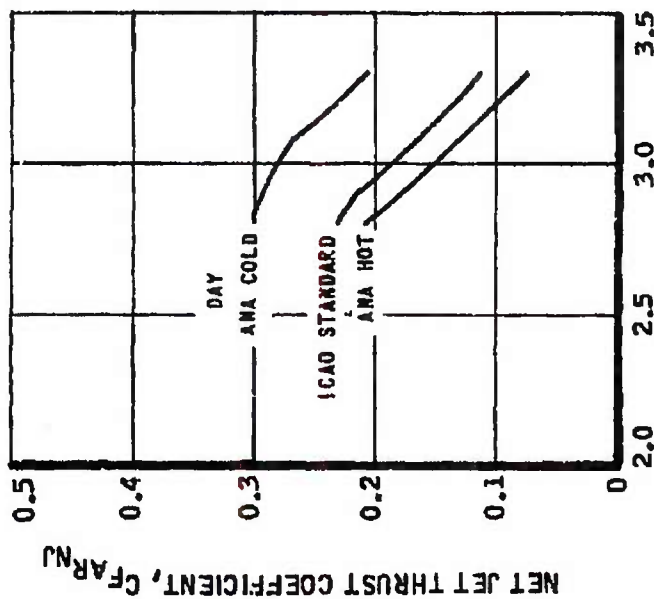
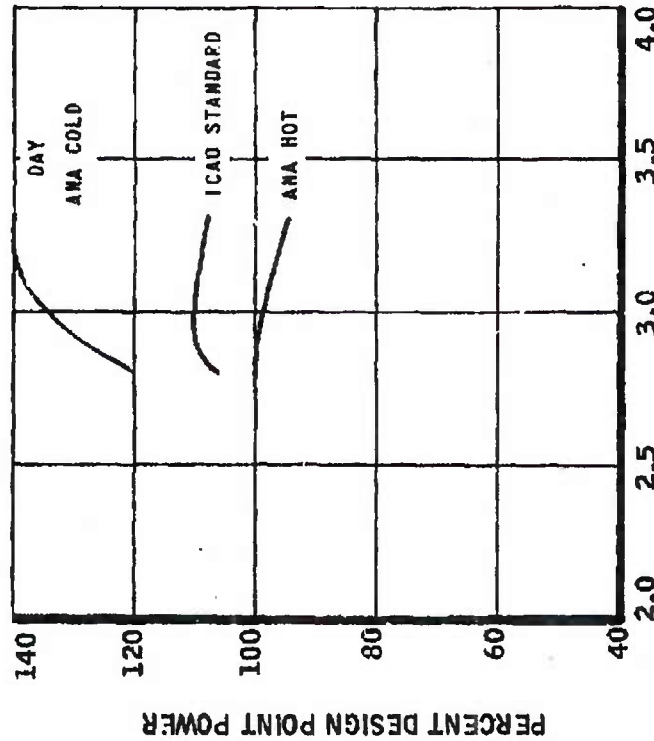
~~ATOMIC ENERGY ACT OF 1954~~



~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

MACQUARDT MODEL MA50-XDA RAMJET  
 ESTIMATED THRUST COEFFICIENT FOR  $T_{W_{max}} = 2960^{\circ}R$   
 ALTITUDE = 1000 ft



FREE STREAM MACH NUMBER,  $M_0$

~~SECRET RESTRICTED DATA~~



THE Marquardt  
 CORPORATION  
 VAN NUYS, CALIFORNIA

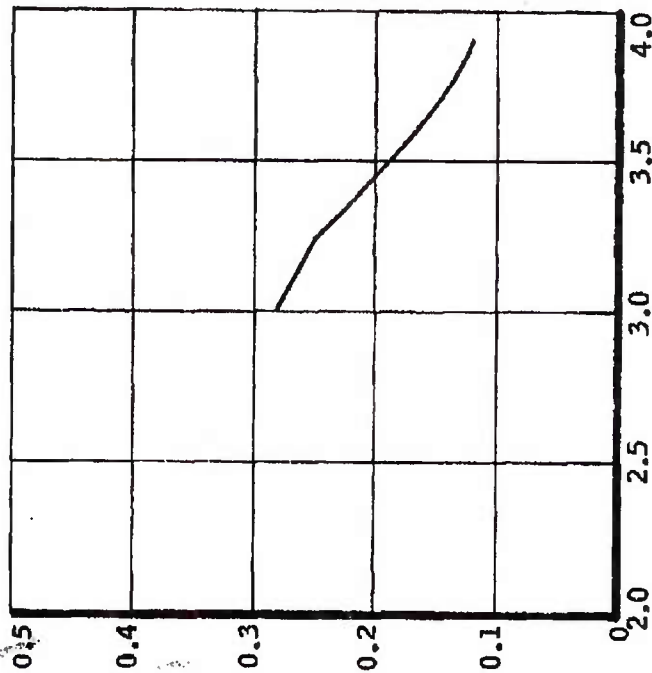
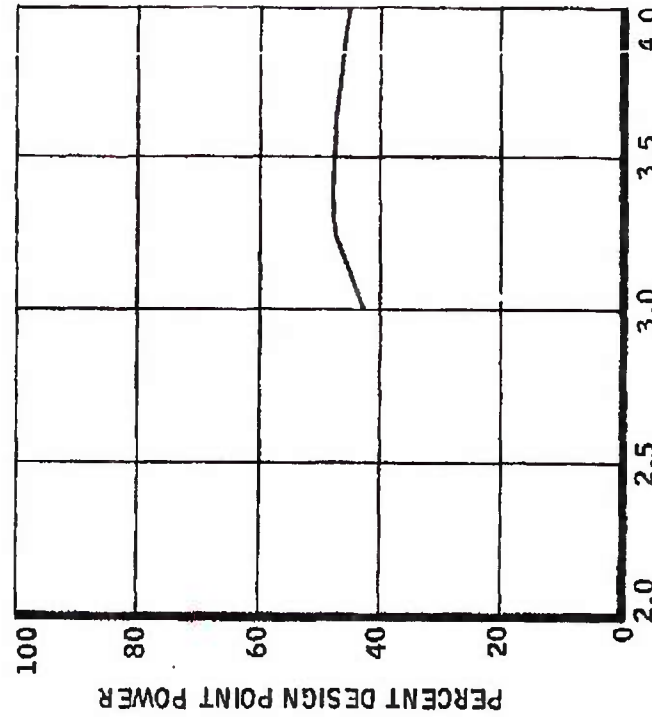
FORM 5876

~~SECRET RESTRICTED DATA~~

ATOMIC ENERGY ACT OF 1954

MARQUARDT MODEL MA50-XDA RAMJET  
 ESTIMATED THRUST COEFFICIENT FOR  $T_{W_{max}} = 2960^{\circ} R$

ICAO STANDARD DAY  
 ALTITUDE = 30,000 ft



FREE STREAM MACH NUMBER,  $M_0$

MAC 4673

~~SECRET RESTRICTED DATA~~

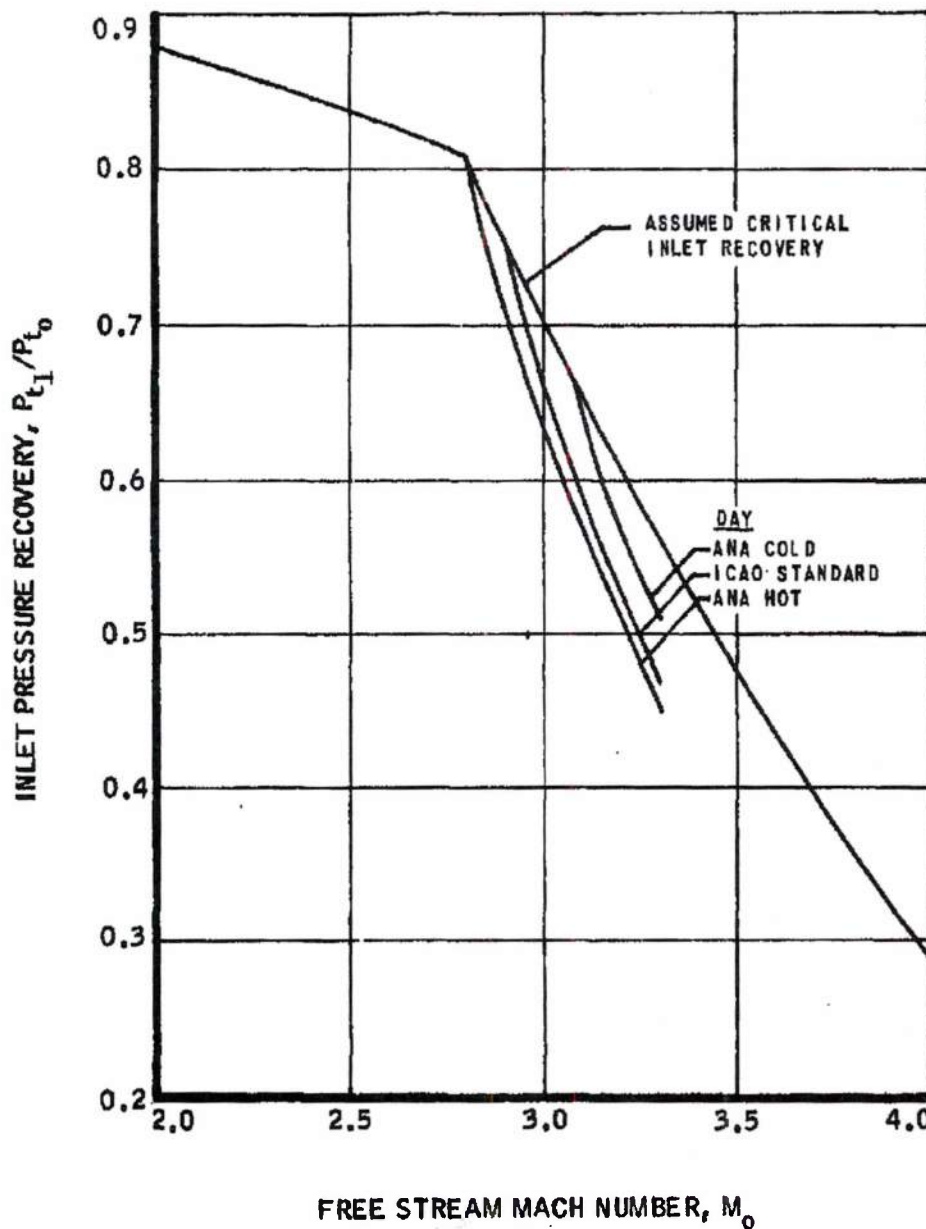
N22E616 ATOMIC ENERGY ACT OF 1954

FIGURE 19

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

MARQUARDT MODEL MA50 XDA RAMJET  
INLET PRESSURE RECOVERY  
ALTITUDE = 1000 ft  
 $T_{Wmax.} = 2960^{\circ} R$



~~SECRET RESTRICTED DATA~~

~~SECRET RESTRICTED DATA~~

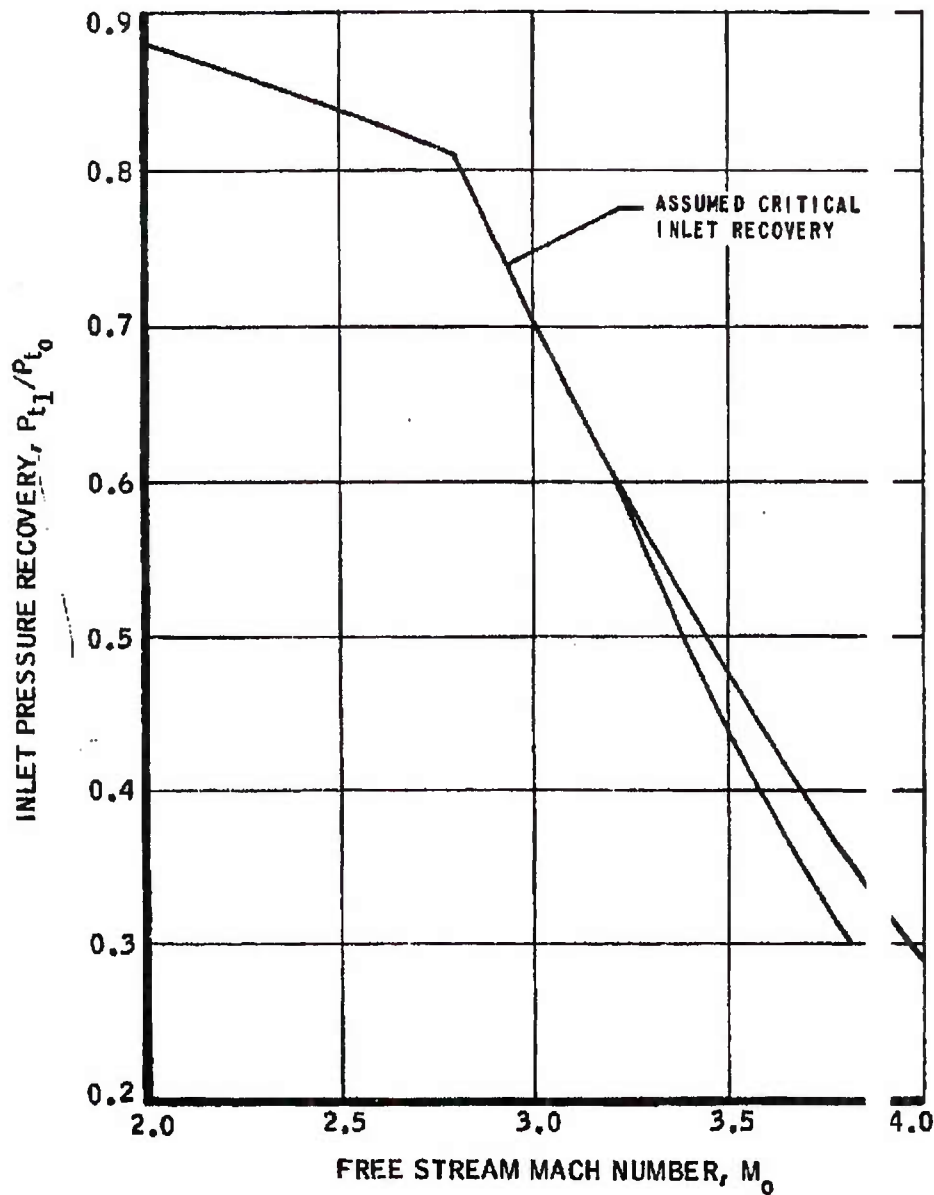
~~ATOMIC ENERGY ACT OF 1954~~

MARQUARDT MODEL MA50-XDA RAMJET  
INLET PRESSURE RECOVERY

ALTITUDE 30,000 ft

$T_{Wmax} = 2960^{\circ} R$

ICAO STANDARD DAY



MAC A63

~~SECRET RESTRICTED DATA~~

N22E618

~~ATOMIC ENERGY ACT OF 1954~~

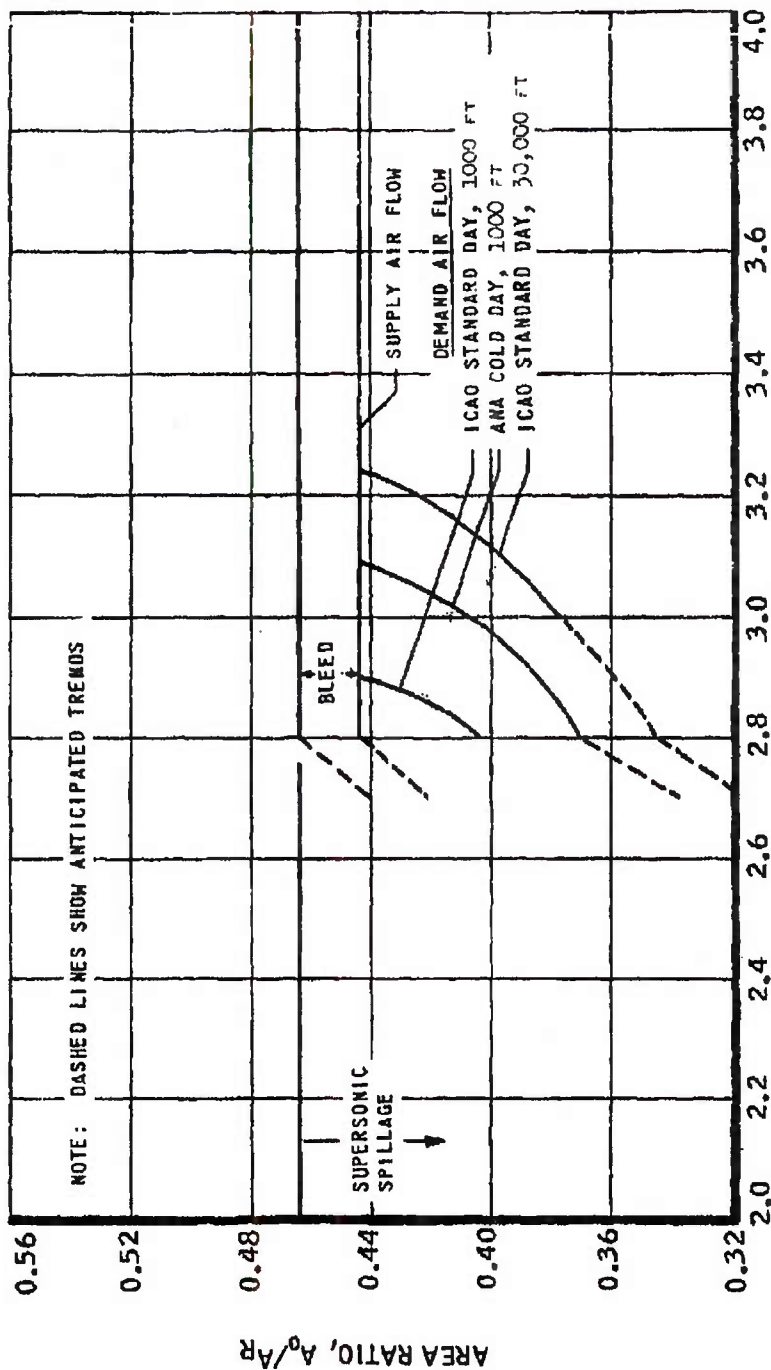
- 35 -

FIGURE 21

~~SECRET RESTRICTED DATA~~

ATOMIC ENERGY ACT OF 1954

MARQUARDT MODEL MA50-XDA RAMJET  
 FREE STREAM CAPTURE AREA RATIO  
 $T_{W_{max}} = 2960^{\circ}R$



~~SECRET RESTRICTED DATA~~

N22E619 ATOMIC ENERGY ACT OF 1954



~~SECRET RESTRICTED DATA~~

MAY 29 2015

~~ATOMIC ENERGY ACT OF 1954~~

**MARQUARDT MODEL MA50-XDA RAMJET**

**DRAG OF ENGINE INSTALLATION**

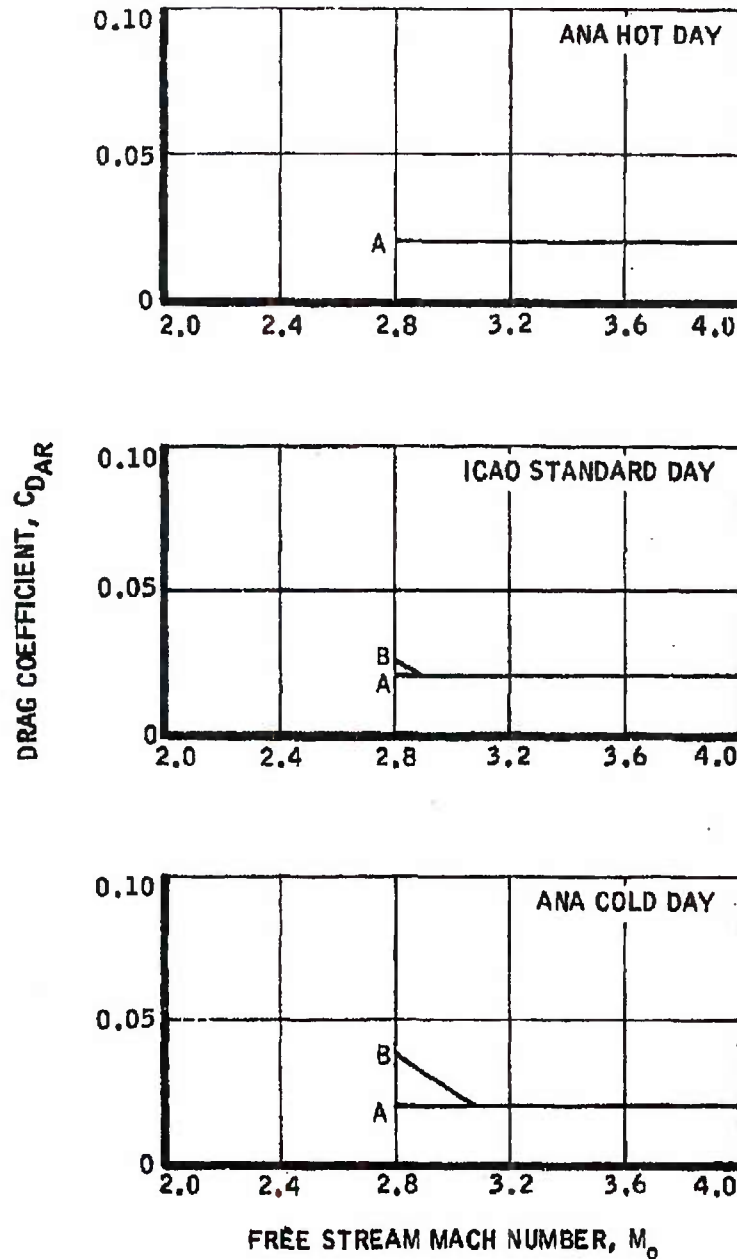
ALTITUDE = 1000 ft

$T_{Wmax} = 2960^{\circ} R$

DRAG COMPONENTS

A - INLET BLEED

B - BYPASS



~~SECRET RESTRICTED DATA~~

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

MARQUARDT MODEL MASO-XDA RAMJET

DRAG OF ENGINE INSTALLATION

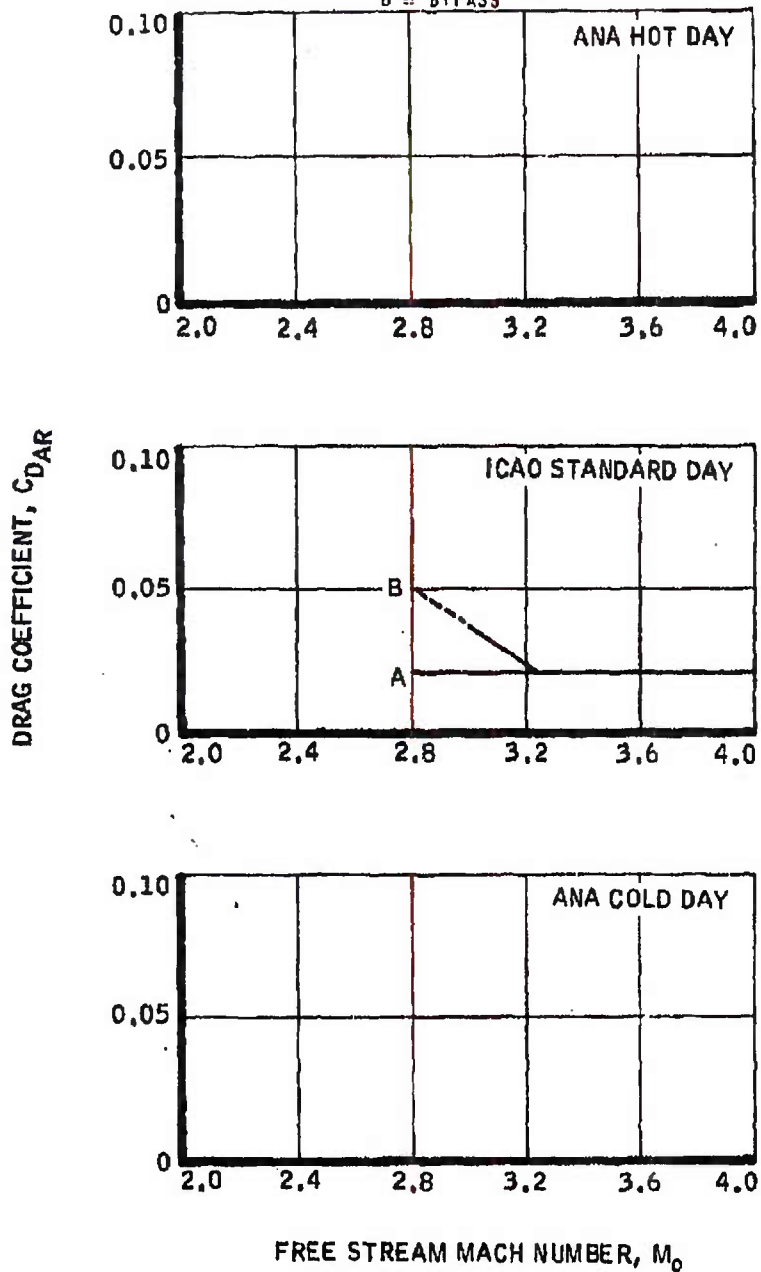
ALTITUDE = 30,000 ft

$T_{W_{max.}} = 2960^{\circ} R$

DRAG COMPONENTS

A = INLET BLEED

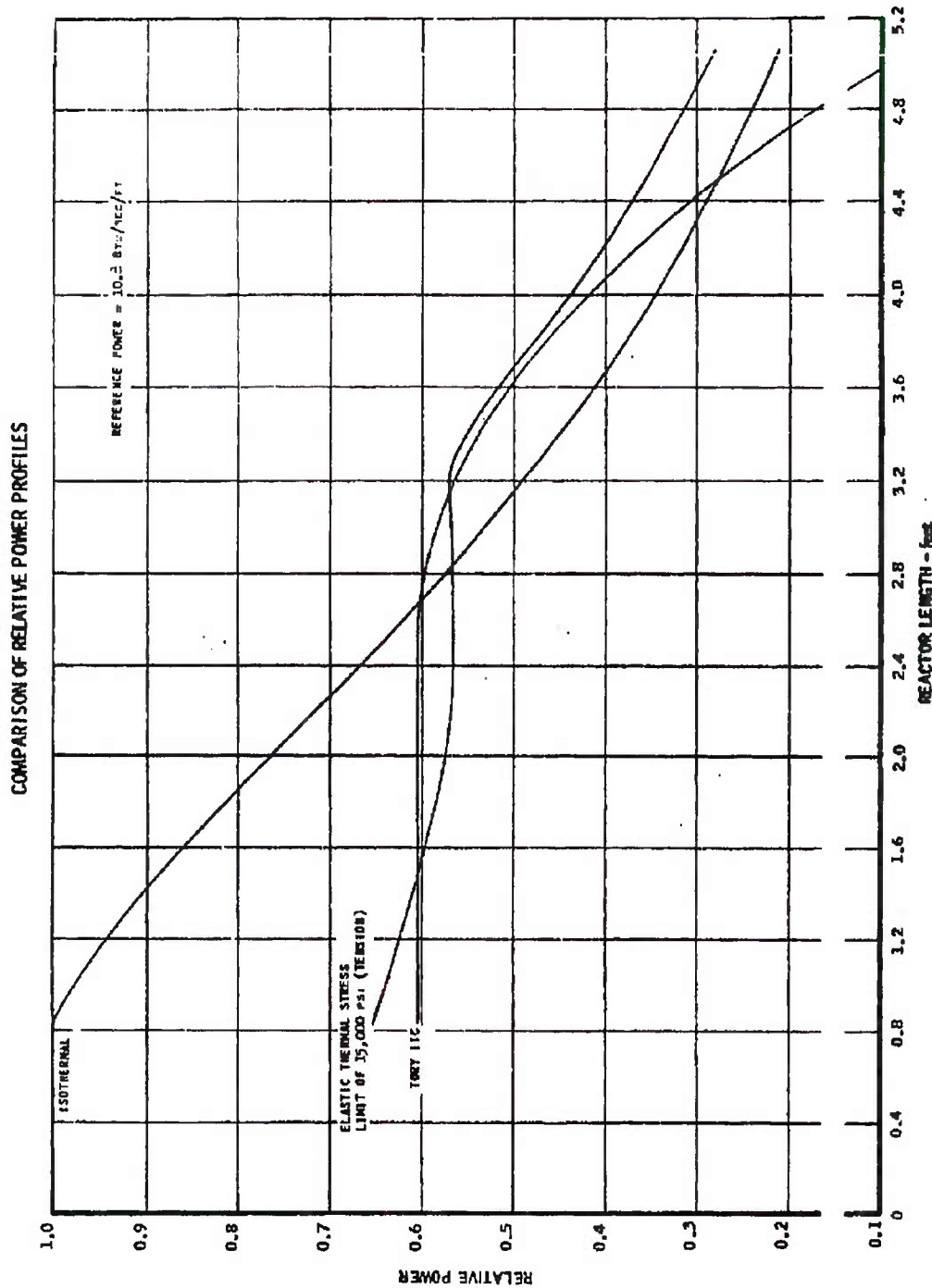
B = BYPASS



~~SECRET RESTRICTED DATA~~

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~



MAC 667

~~SECRET RESTRICTED DATA~~

N22E619

~~ATOMIC ENERGY ACT OF 1954~~

- 39 -

FIGURE 25



~~SECRET RESTRICTED DATA~~

REPORT 56

~~ATOMIC ENERGY ACT OF 1954~~

and wall temperature. This change in power profile results in an improvement of thrust coefficient of 2.5 percent for the basic Model MA50-XCA propulsion system.

(2) A change similar to (1) above, wherein the elastic thermal stress is raised to 18,000 psi. The change in power profile for this core results in a 5 percent increase in thrust coefficient for the basic Model MA50-XCA. This increase in elastic thermal stress limit is considered feasible on the basis of successful operation of the Tory IIC core at thermal stresses above 20,000 psi.

(3) A change in the number of tie tubes. The number of tie tubes for the Tory IIC is determined principally by the diameter of the billet used for the Tory IIC base plate. LRL now believes that advancements in fabrication techniques may permit an increase in billet diameter from 5 to 9 inches. Inasmuch as the present tie tube design point temperature is relatively low, LRL believes the number of tie tubes may be reduced by the ratio of the billet diameters (5/9). When the number of tie tubes is reduced, the reactor frontal area previously occupied by tie tube and unfueled region is replaced by fueled core tubes. Reduction in the number of tie tubes as outlined above will permit a thrust coefficient increase of 2.5 percent for the basic Model MA50-XCA propulsion system.

(4) An increase in the fueled core tube diameter. A fueled core tube diameter increase from 0.227 to 0.230 inches, for the same fuel element size, increases the core void fraction by 2.5 percent. This change results in a 1 percent increase in thrust coefficient for the basic Model MA50-XCA propulsion system.

(5) A reduction in the cooling airflow per tube. Inasmuch as the Tory IIC tie tubes are running cool (1250°F), the cooling airflow per tube may be reduced. This reduction has been accomplished by reducing the inside diameter of the tie tube while keeping other tie tube dimensions and geometry fixed. A reduction of tie tube inside diameter to 0.325 inches increases the tie tube temperature to 1650°F, and the thrust coefficient change is 0.5 percent. This change is invalidated when the number of tie tubes is reduced, as in Item (3) above.

LRL has indicated feasibility concurrence on the changes listed above. Future work will include analysis of effects on propulsion system performance of combining individual concepts to determine whether individual results are additive and to determine the most feasible manner of increasing system performance. Mechanical design, heat transfer, structural analysis, and neutronic studies will be made in areas showing the most promising performance gain.

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~





~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

### 3.2.2 Inlet Survey and Performance Analysis

The design considerations for the nuclear ramjet propulsion system are unique. The air temperature rise across the reactor is limited by the maximum permissible operating temperature of the reactor core material. The low heat addition per unit frontal area of the reactor and the characteristically large reactor pressure drops are indicative of low thrust coefficients. In particular, the installed thrust-over-missile drag margin is low and is therefore quite sensitive to inlet pressure recovery and installed drag characteristics.

The requirement for maximum inlet pressure recovery combined with low drag is met by the use of internal contraction. Unfortunately, the internal contraction inlet required some form of variable geometry to permit inlet starting (swallowing of terminal shock) as well as internal bleed to maintain high pressure recovery. The 1961 program has been directed towards experimental verification of assumed inlet pressure recoveries, required bleed rates, inlet air-flow characteristics, and installed drag characteristics.

The original objective of the 1961 experimental program, as presented in Reference 5, was the design and fabrication of two small scale inlet test models. It was planned that the first inlet be tested during 1961 and the second in 1962. Inlet design for both models was to be based upon the external-internal compression type described in Reference 6. (This inlet has demonstrated good pressure recovery characteristics for modest bleed rates, and is easily controlled as to variable spike position as well as internal shock position-bypass operation). The inlets were to be underslung beneath the missile body and to incorporate the S-shaped subsonic diffuser ducting. The first inlet was to be axially symmetric as far as the supersonic compression surfaces were concerned, while the second inlet was to be asymmetric and partially wrapped about the lower fuselage contour. The choice between the two inlet configurations was to be based upon calculation of a net thrust-minus-installed drag value using the pressure recovery and drag measurements obtained.

On 18 April 1961, a coordination meeting was held at ASD, Dayton, Ohio, with the aerothermodynamics contractor and Marquardt as participants. At this meeting it was ruled that the experimental inlet test program be a joint effort between Marquardt and the aerothermodynamics contractor. Lines for the aerodynamic models were to be mutually agreeable. Marquardt was given the responsibility for model design and fabrication and performance of the test program including data reduction. As a result of these decisions, coordination meetings were held between Marquardt and the aerothermodynamics contractor for the

MAC ASD

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

MAY 29 2015



~~SECRET RESTRICTED DATA~~

REPORT 587

~~ATOMIC ENERGY ACT OF 1954~~

purpose of establishing test inlet configurations. The principal change in the original test plan has been the elimination of the design and fabrication of the asymmetric inlet and the substitution of an alternate axisymmetric inlet. The alternate inlet was selected on the basis of less sensitivity to angles of attack and yaw than the basic inlet.

Lines for the basic inlet are shown schematical in Figure 26. Through the use of a finite initial cone followed by an isentropic turning surface, external supersonic compression from Mach 2.8 to about Mach 2.2 is achieved with only a 1 percent loss in total pressure. Additional supersonic compression as well as supersonic turning are effected internally. This is accomplished by the reflection of two finite oblique shocks off the cowl in conjunction with a flow bleed slot on the centerbody. The bleed slot removes the boundary layer prior to the adverse pressure gradient associated with the internal compression. A translating spike is used to permit inlet start and to obtain high pressure recovery during off-design operation while minimizing drag. To use an inlet of this type effectively, the configuration must be optimized on a net thrust-minus-drag basis. An optimization procedure was performed in Reference 7 wherein the pressure recovery (and, therefore, thrust) of several combinations of isentropic turning, cowl angles, and attendant cowl drags were determined. The results of this study are shown in Figure 27. The net thrust-minus-cowl drag is shown as a function of cone surface Mach number and flow turning at the cowl.

This optimization study for the basic inlet was revised in Reference 8 to account for more realistic subsonic diffuser losses. This revision permitted increased flow turning at the cowl and therefore improved cowl drag. The net thrust-minus-cowl drag of Figure 27 was increased from 0.233 to 0.240 by this analysis. The final basic inlet configuration is summarized by the following parameters (see Figure 26):

$\theta_1$	14.48°	$\theta_3$	5.14°
$\theta_2$	20.97°	$\theta_4$	4.86°
$\phi$	25.97°	$M_3$	1.72
$MS_1$	2.37	$M_4$	1.37
$MS_2$	2.13	$M_5$	0.753
$\overline{M}_2$	2.17	Bleed	4.5 percent

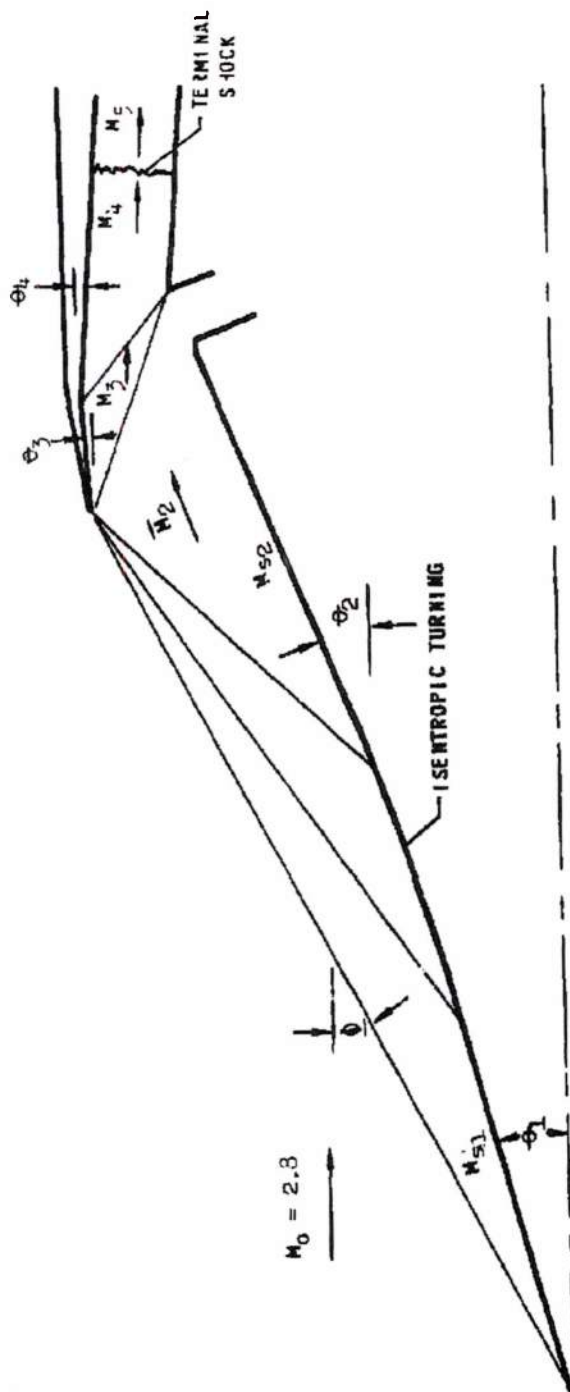
Estimated performance for the basic inlet is shown in Figure 1, as a function of free stream Mach number for conditions of zero angle of attack and yaw. This performance is based upon the spike position variation shown in Figure 28. During boost, the spike is translated forward 6 inches to reduce the

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

~~UNCLASSIFIED~~

AXISYMMETRIC, EXTERNAL-INTERNAL COMPRESSION INLET



MAC A63

~~UNCLASSIFIED~~

N22B44

-43-

FIGURE 26

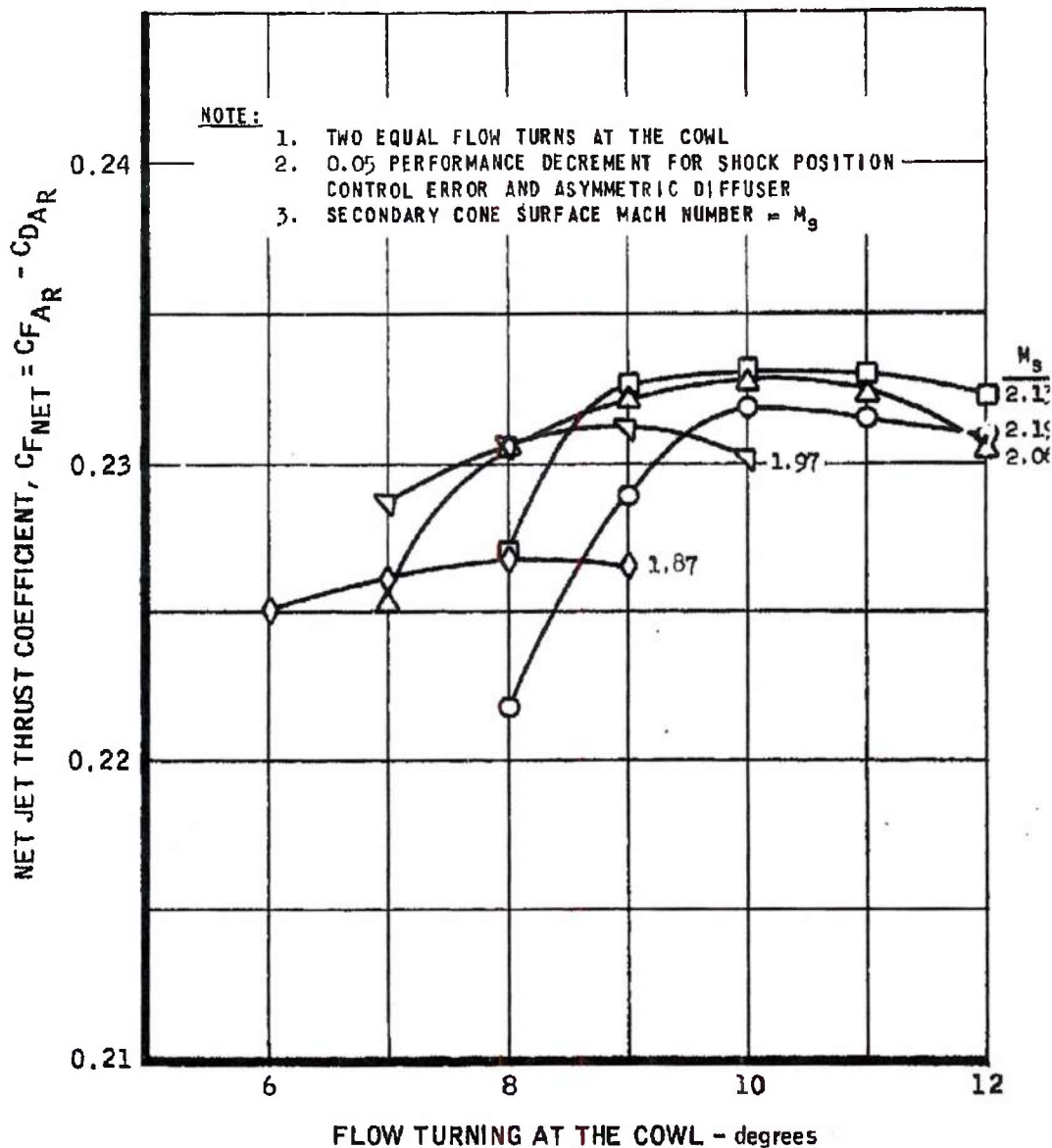
MAY 29 2015



REPORT 58

UNCLASSIFIED

# OPTIMIZATION OF MACH 2.8 AXISYMMETRIC INLET



UNCLASSIFIED

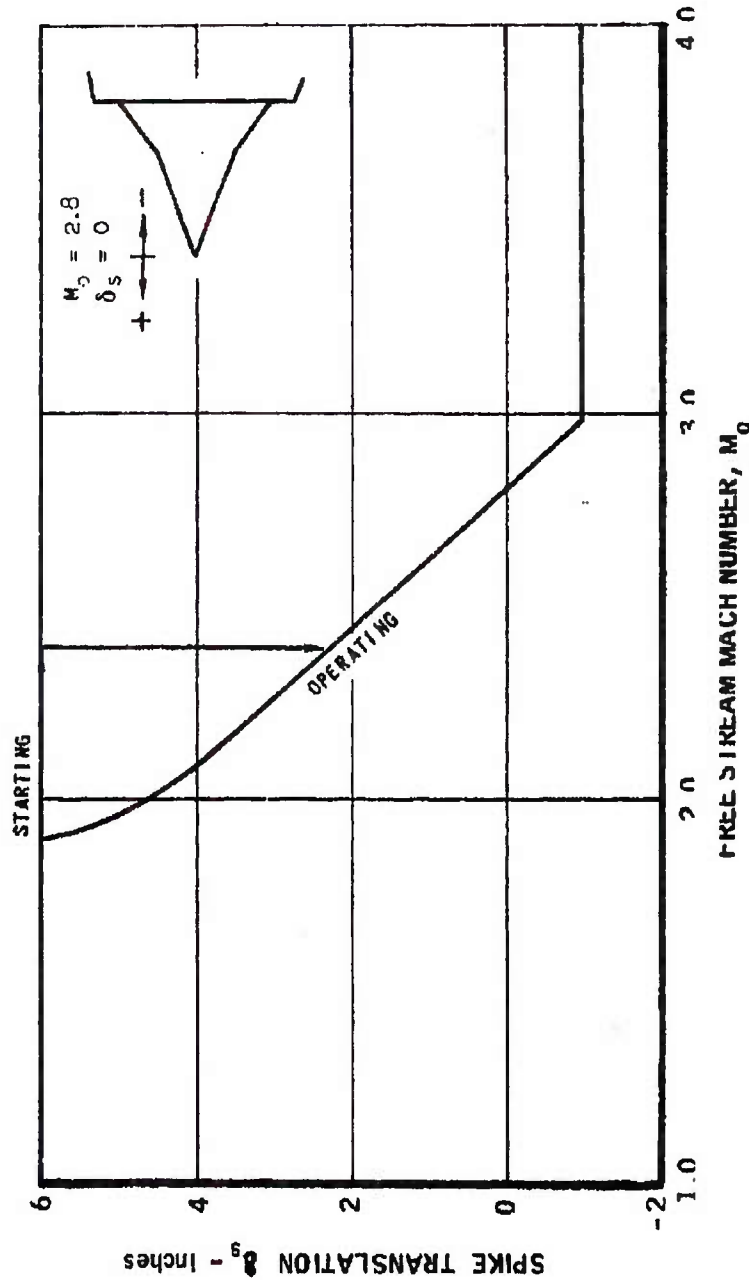


*Morguardt*  
 VAN NUYS, CALIFORNIA

UNCLASSIFIED

5876

VARIABLE INLET OPERATION  
 AT 0° ANGLE OF ATTACK AND YAW



MAC 6073

UNCLASSIFIED

22E597

-45-

FIGURE 28



~~SECRET RESTRICTED DATA~~

REPORT 58

~~ATOMIC ENERGY ACT OF 1954~~

internal contraction, as indicated in Figure 29. In this position the inlet will swallow the terminal shock at a free stream Mach number of about 2.4. Following this, the inlet spike position is varied continuously (operating line) between Mach 3.0 and 1.9 to keep the first lip shock on the rim of the centerbody bleed slot.

Details of the alternate inlet have been agreed upon by representatives of Chance Vought and Marquardt. This inlet differs from the basic inlet in that the compression fan from the inlet spike will not be focused on the lip but rather will be spread out and reflected from the cowl inner surface. The comparison of the inlet types is shown schematically in Figure 30. The alternate inlet is longer and has a shallower initial cowl angle. It is anticipated that the alternate inlet will require less bleed and will be less sensitive to perturbations in angle of attack and yaw. Its performance at zero angle of attack and yaw is expected to be about equivalent to the basic inlet. The inlet test program is further discussed in Section 3.8.1

### 3.2.3 Exhaust Nozzle Aerodynamics

The Marquardt role of integrating the propulsion system into a predictable, reliable, and efficient system has required a concentrated effort on the exit nozzle during 1961. This effort is prompted by the inherently low thrust-to-drag margin of the missile system, which imposes stringent requirements on the accuracy of nozzle performance predictions. Nozzle efficiency must be high (a 98 percent velocity coefficient is assumed for calculation purposes), nozzle drag loads must be known, and nozzle cooling air must be handled efficiently. It is recognized that experimental tests of the exhaust nozzle were necessary to supply the required design information. The nozzle length-to-area ratio selected for the installation must be based upon net thrust-minus-installed drag characteristics rather than upon nozzle jet thrust alone. Thus, efficient handling of engine and exit nozzle cooling air must be accomplished, and nozzle shroud boattail and base drags must be considered in establishing the overall exit nozzle geometry.

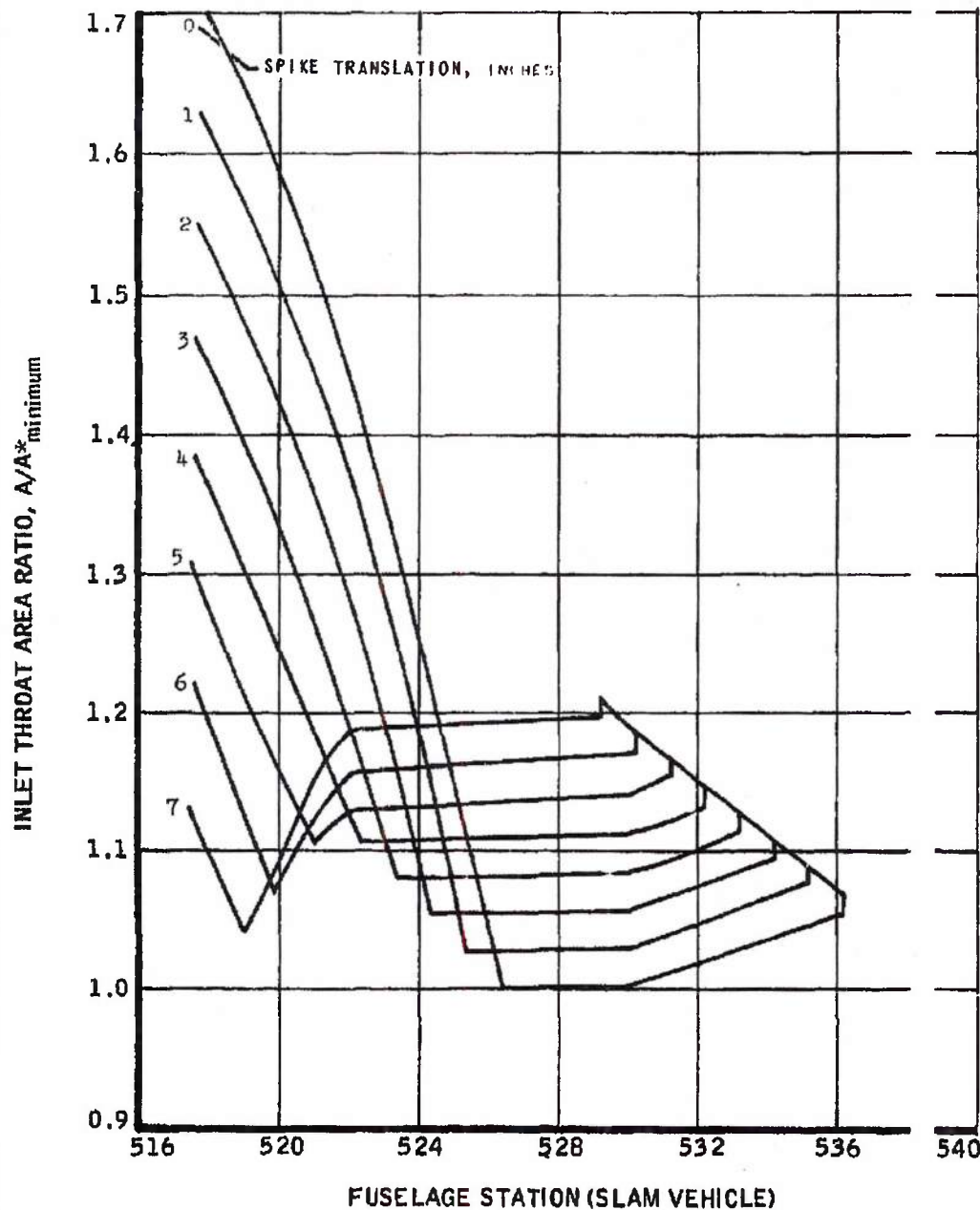
The types of nozzle configurations analyzed during the year are shown in Figure 31. In Figure 31A the engine cooling air between the reactor and pressure vessel is mixed with the reactor air and passed through a common nozzle. The engine cooling airflow must be throttled to prevent flow starvation through the reactor. While this configuration has about the same net jet thrust as the other configurations studied (see Section 3.8.2), analysis of this system was limited pending the demonstration of successful coatings necessary for the radiation cooled nozzle. In Figure 31B the engine cooling air is collected

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

~~CONFIDENTIAL~~

### VARIATION OF INLET AREA RATIO WITH SPIKE TRANSLATION



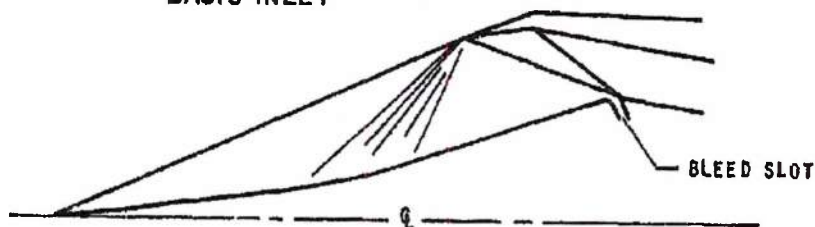
MAC 603

~~CONFIDENTIAL~~

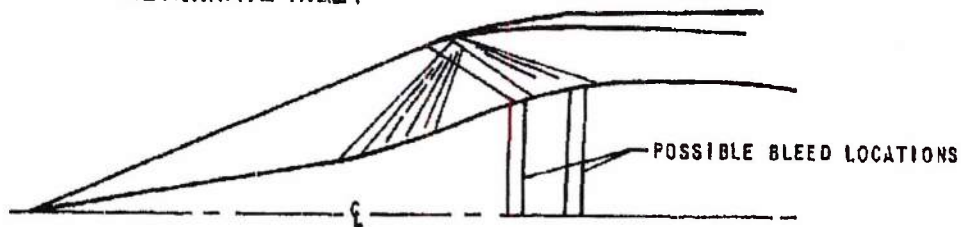
UNCLASSIFIED

### COMPARISON OF INLET TYPES

BASIC INLET



ALTERNATE INLET



BAC 673

UNCLASSIFIED

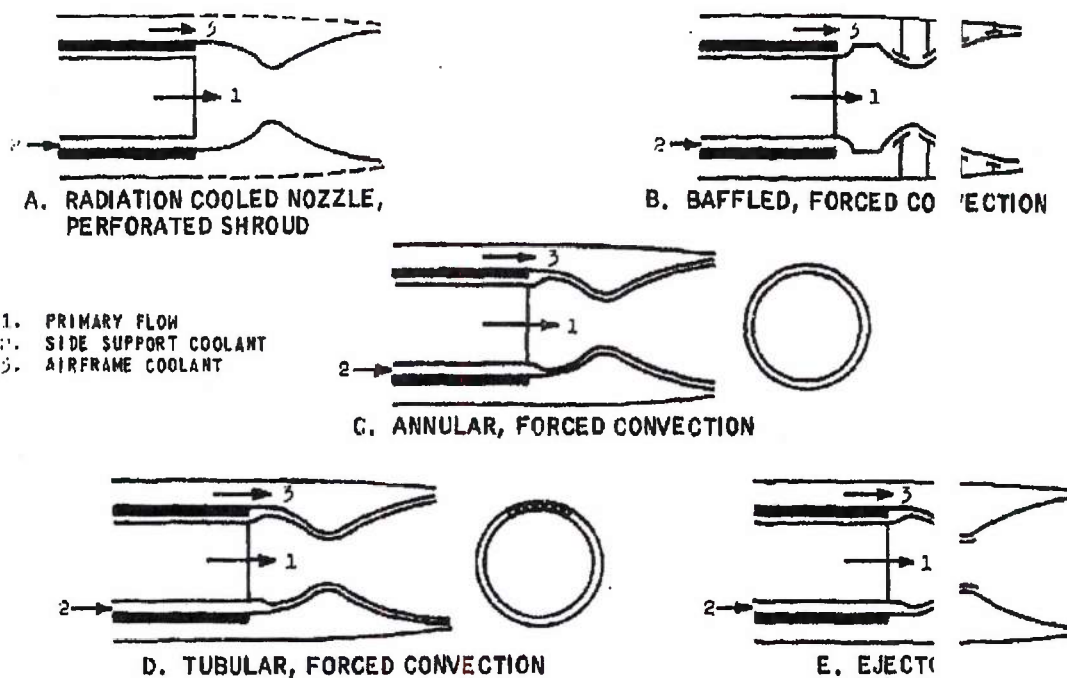


*Marquardt*  
 VAN NUYS, CALIFORNIA

QNT 5876

~~SECRET~~

### TYPICAL EXHAUST NOZZLE INSTALLATIONS



MAC 657

~~SECRET~~  
 NI5B331



~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

exterior to the nozzle and is baffled to provide cooling at critical areas of the nozzle. This forced convection cooling scheme was eliminated in favor of the configuration of Figure 31C, because it appeared that the pressure drop of the cooling air was excessive. The configuration of Figure 31C employs forced convection in an annular passage and performs the function of the baffled arrangement more efficiently. Figure 31D shows a forced convection model in which the nozzle wall is formed from small coolant channels similar to those used in regeneratively cooled rocket nozzles. Finally, configuration 31E indicates another approach in which the engine cooling air is used to supply the secondary flow of an ejector type nozzle. Film cooling is used on the divergent portion of the nozzle.

#### Nozzle Sizing

In order to design, test, and evaluate exhaust nozzle models during the 1961 time period, it was necessary to make a preliminary study of the nozzle configuration to establish basic nozzle sizing relationships. From the Model MA50-XCA propulsion system optimization at design point, it was determined that the effective nozzle area expansion is 2.58 for a fully expanded nozzle with an operating pressure ratio of 15.2. These data also indicated that the influence coefficient of the nozzle on the Model MA50-XCA propulsion system performance was 4.8 percent change in thrust for each percent of nozzle velocity coefficient. A nozzle-boattail optimization was performed in Reference 8, wherein it was established that the optimum installation on a net jet thrust-minus-boattail drag basis would call for a nozzle overexpansion of about 13.2 percent as shown in Figure 32. The cooling air drag losses were neglected in this analysis inasmuch as this drag is essentially constant for a given type of configuration.

#### Nozzle Aerodynamic Lines

Nozzle aerodynamic lines from the method of characteristics were determined as presented in Reference 9. Nozzles both longer and shorter than the basic nozzle were described for test, because it was believed that knowledge of the variation of the internal nozzle performance with nozzle length would aid in future nozzle configuration studies. Characteristics of the forced convection primary nozzle are listed in Table 4, and nozzle coordinates are specified in Figure 33. The annular type coolant passage of Figure 31C was designed for testing with the basic nozzle to establish the pressure drop relations for such a system. The tubular nozzle configuration of Figure 31D could not be tested due to the small scale of the models. The ejector type configuration of Figure 31E was designed and is shown in Figure 34. This nozzle is again the same length and has the same area ratio as the basic optimized nozzle. Model tests of these

~~SECRET RESTRICTED DATA~~

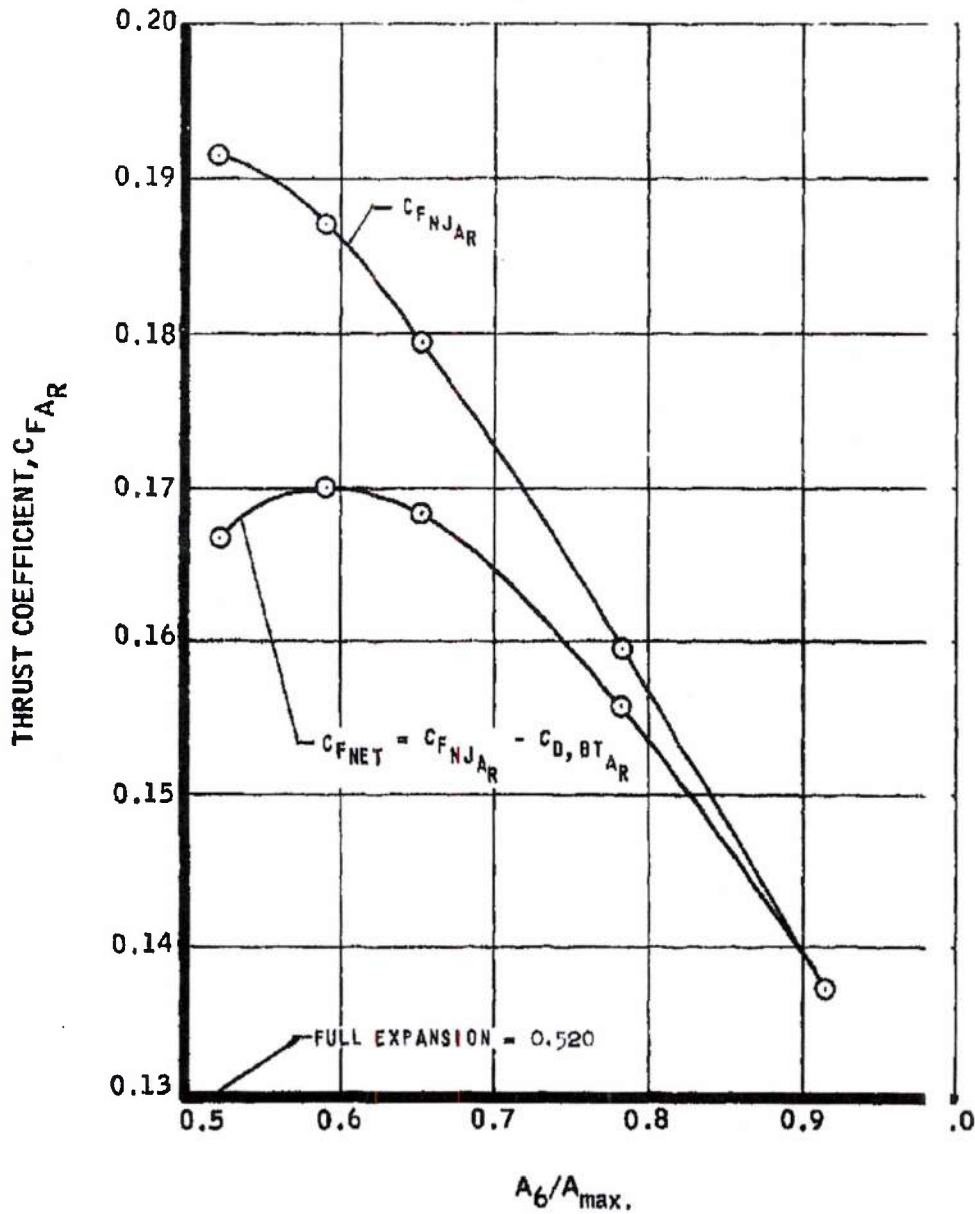
~~ATOMIC ENERGY ACT OF 1954~~

UNCLASSIFIED



5876

# NOZZLE-BOATTAIL OPTIMIZATION FOR MA50-XCA ENG IE AT DESIGN POINT



MAC 1632

UNCLASSIFIED

22F598

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

TABLE 4  
 FORCED CONVECTION CONFIGURATIONS

Configuration	Nozzle Area Ratio $A_6/A_5$	Length Ratio	Design Pressure Ratio Hot Condition	Design Pressure Ratio $\gamma = 1.4$	Comments
F. C. No. 1	3.567	1.00	2.2	28.0	Basic Clipping Nozzle
F. C. No. 2	3.220	0.60	21.5	23.8	Intermediate Nozzle
F. C. No. 3	2.929	0.48	18.5	20.3	MA50-XCA Optimized Nozzle
F. C. No. 4	2.580	0.39	15.2	16.5	MA50-XCA Fully Expanded Nozzle

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~



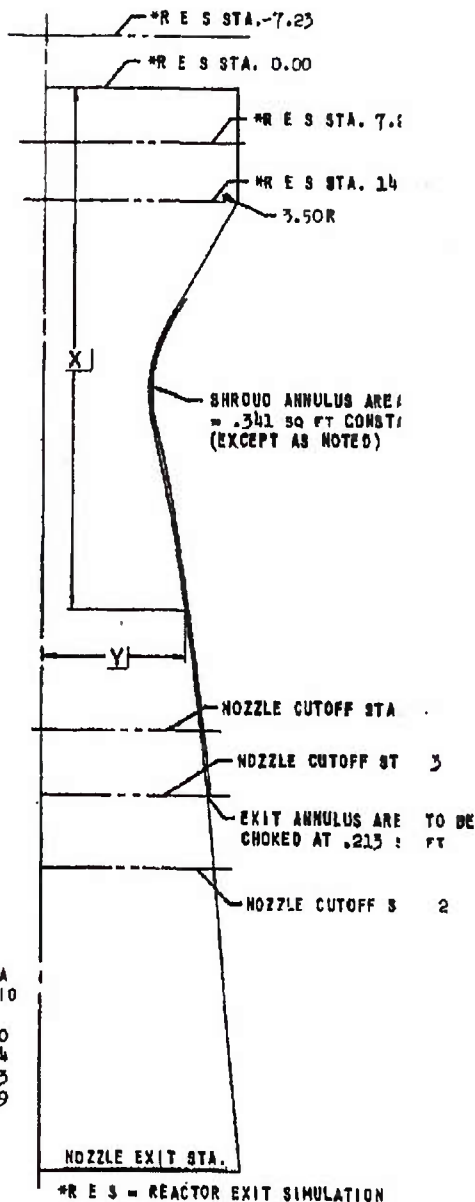
~~CONFIDENTIAL~~

# FORCED CONVECTION CONFIGURATION OF EXHAUST NOZZLE

X	Y
0.	27.56
14.46	27.56
25.73	21.53
32.44	17.61
41.44	15.20
41.94	15.20
43.73	15.29
45.53	15.57
46.79	15.84
49.80	16.58
52.81	17.32
55.83	18.08
58.83	18.83
61.84	19.61
64.85	20.40
67.86	21.14
70.87	21.84
73.88	22.48
76.89	23.04
79.90	23.56
82.91	24.07
85.92	24.54
88.93	25.00
91.94	25.40
94.94	25.81
96.60	26.02
97.95	26.18
100.96	26.51
103.97	26.84
109.99	27.33
116.01	27.75
122.03	28.10
128.05	28.37
134.07	28.59
140.09	28.72
146.11	28.79
153.03	28.83

CONFIGURATION	NOZZLE LENGTH X (INCHES)	AREA RATIO
F C NO. 1	153.03	3.60
F C NO. 2	109.99	3.24
F C NO. 3	96.60	2.93
F C NO. 4	85.29	2.59

REFERENCE:  
 MARQUANDT DWD. NO. X81289



MAC 467

~~CONFIDENTIAL~~

N22B45

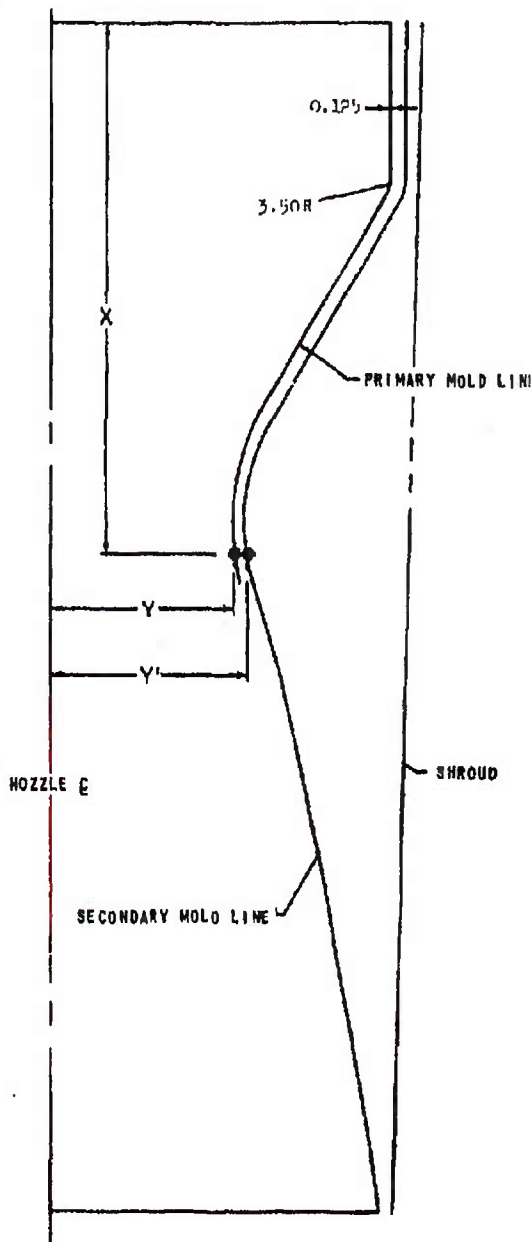
CONFIDENTIAL

# FACTOR CONFIGURATION OF EXHAUST NOZZLE

CONFIGURATION E I  
 NOZZLE LENGTH 10.000 IN.  
 AREA RATIO 1.000

X	Y	Y'
0	27.00	
1.00	27.00	
2.00	27.00	
3.00	27.00	
4.00	27.00	
5.00	27.00	
6.00	27.00	
7.00	27.00	
8.00	27.00	
9.00	27.00	
10.00	27.00	
11.00	27.00	
12.00	27.00	
13.00	27.00	
14.00	27.00	
15.00	27.00	
16.00	27.00	
17.00	27.00	
18.00	27.00	
19.00	27.00	
20.00	27.00	
21.00	27.00	
22.00	27.00	
23.00	27.00	
24.00	27.00	
25.00	27.00	
26.00	27.00	
27.00	27.00	
28.00	27.00	
29.00	27.00	
30.00	27.00	
31.00	27.00	
32.00	27.00	
33.00	27.00	
34.00	27.00	
35.00	27.00	
36.00	27.00	
37.00	27.00	
38.00	27.00	
39.00	27.00	
40.00	27.00	
41.00	27.00	
42.00	27.00	
43.00	27.00	
44.00	27.00	
45.00	27.00	
46.00	27.00	
47.00	27.00	
48.00	27.00	
49.00	27.00	
50.00	27.00	
51.00	27.00	
52.00	27.00	
53.00	27.00	
54.00	27.00	
55.00	27.00	
56.00	27.00	
57.00	27.00	
58.00	27.00	
59.00	27.00	
60.00	27.00	
61.00	27.00	
62.00	27.00	
63.00	27.00	
64.00	27.00	
65.00	27.00	
66.00	27.00	
67.00	27.00	
68.00	27.00	
69.00	27.00	
70.00	27.00	
71.00	27.00	
72.00	27.00	
73.00	27.00	
74.00	27.00	
75.00	27.00	
76.00	27.00	
77.00	27.00	
78.00	27.00	
79.00	27.00	
80.00	27.00	
81.00	27.00	
82.00	27.00	
83.00	27.00	
84.00	27.00	
85.00	27.00	
86.00	27.00	
87.00	27.00	
88.00	27.00	
89.00	27.00	
90.00	27.00	
91.00	27.00	
92.00	27.00	
93.00	27.00	
94.00	27.00	
95.00	27.00	
96.00	27.00	
97.00	27.00	
98.00	27.00	
99.00	27.00	
100.00	27.00	

REFERENCE:  
 MARQUARDT DWG. NO. X81200



MAC A63

CONFIDENTIAL



~~SECRET RESTRICTED DATA~~

REPORT 5876

~~ATOMIC ENERGY ACT OF 1954~~

configurations have been conducted at the FluidDyne Engineering Corporation Facilities at Elk River, Minnesota. Ninety-eight percent nozzle velocity coefficients have been recorded on all configurations tested. Results are further discussed in Section 3.8.2.

#### Aerothermodynamics of Nozzle Coolant Tubes

To analyze properly the installed characteristics of the coolant-tube forced convection nozzle of Figure 31D, it is necessary to determine the aerothermodynamics of the cooling tubes. A computer program, Rita, was written to solve the aerothermodynamics of the curved coolant tube by the method of finite differences. This program solves the heat transfer, friction, and Mach number rise equations for a heated, curved tube of variable cross-sectional shapes and variable areas. This program was described in Reference 7.

Typical results of this program are as follows: A 3/4-inch internal diameter tube was fitted to the nozzle contour of Figure 33. For this tube diameter, there is a total of 240 tubes forming the nozzle. For a total airflow of 113 lb/sec, each tube passes 0.47 lb/sec. The Mach number entering the tubes was 0.25. For these conditions the total pressure loss in the tube was about 22 percent, the gas temperature rise was 183°F, and the maximum tube wall temperature was 1500°F, occurring at the tube exit.

Program Rita has also been used to predict the pressure drops in the annular forced convection configuration. These relations are used to aid in the establishment of the optimum nozzle installation as discussed in a later section of this report.

#### Nozzle Off-Design Performance

During the initial boost phase the ramjet exhaust nozzle must operate as an unchoked (subsonic) nozzle. Similarly, at other points inside the operating envelope the nozzle, although choked, may operate at pressure ratios sufficiently low to permit nozzle separation. Both of these conditions invalidate the one-dimensional choked flow relationships assumed in the original machine programs.

In Reference 7, a computer program was described where a ramjet performance criteria during the initial boost phase could be determined. This program, Nina, has been successfully run for the boost trajectory shown in Reference 10. The latest boost trajectory of the aerothermodynamic contractor

MAC 483

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

presented in Reference 11 has not been analyzed because the boost trajectory has not been finalized for a missile sized to perform the ADO No. 11 mission.

Also presented in Reference 7 was the method of incorporating the experimental nozzle results into the computer program for more realistic thrust prediction at off-design conditions. These changes will be incorporated in the performance predictions next year.

#### Nozzle Configuration Studies

The aerodynamic analysis of the exhaust nozzle for the Model MA5 XCA engine has been handled at design point (Mach 2.8; ANA 421 Hot Day; altitude 1,000 feet) in two general categories. The more obvious was the investigation of the primary propulsion nozzle, while the other was the performance evaluation of the various cooling flows. The design criteria and techniques used to derive the basic optimized primary nozzle contour were presented in Reference 9 and discussed briefly above. The performance analysis of the primary flow will be presented in the configuration study results to follow.

During the year, five techniques of nozzle cooling have been considered as shown in Figure 31. Performance studies of the four more promising configurations have been completed. These studies include the effect on net engine thrust of the primary nozzle flow, the engine cooling flow, the airframe cooling flow, and the afterbody drag. The four configurations evaluated as installed systems were:

- (1) The annular, forced convection nozzle
- (2) The tubular, forced convection nozzle
- (3) The ejector nozzle
- (4) The radiation cooled nozzle

With the first two configurations, the reactor side support cooling flow was maintained completely separated from the nozzle primary flow, while with the third configuration, this cooling flow was introduced into the primary stream in the divergent section of the nozzle (just downstream of the primary nozzle throat). With the fourth configuration, the cooling flow was mixed with the primary flow upstream of the nozzle.

In the first two configurations listed above, the cooling flow drag was minimized by expanding the secondary exhaust flow to equal the primary nozzle exhaust pressure with a convergent-divergent nozzle arrangement. The analysis

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~



~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

of each configuration was directed toward the definition of a nozzle thrust coefficient for each flow that was then used to establish the installed engine net thrust coefficient including the nozzle afterbody and base drag.

The engine net thrust coefficient was expressed as:

$$C_{TN} = C_{TP} + C_{TS} + C_{TA} + C_{TBT} + C_{Tb}$$

The net thrust coefficient of the primary nozzle flow is given by:\*

$$C_{TP} = 2 \left[ \frac{A_{oP}}{A_R} \left( C_{VP} \frac{V_{eP}}{V_o} - 1 \right) + \frac{1}{\gamma_o M_o^2} \left( \frac{A_{eP}}{A_R} \right) \left( \frac{P_{eP}}{P_o} - 1 \right) \right]$$

The net thrust equation for the secondary (engine cooling) flow is:

$$C_{TS} = 2 \left[ \frac{A_{oS}}{A_R} \left( C_{VS} \frac{V_{eS}}{V_o} - 1 \right) + \frac{1}{\gamma_o M_o^2} \left( \frac{A_{eS}}{A_o} \right) \left( \frac{P_{eS}}{P_o} - 1 \right) \right]$$

The net thrust equation for the airframe cooling flow is:

$$C_{TA} = 2 \left[ \frac{A_{oA}}{A_R} \left( C_{VA} \frac{V_{eA}}{V_o} - 1 \right) + \frac{1}{\gamma_o M_o^2} \left( \frac{A_{eA}}{A_o} \right) \left( \frac{P_{eA}}{P_o} - 1 \right) \right]$$

The exhaust velocities,  $V_e$ , of each of the flows were the local velocities computed from the local properties at the beginning of each flow expansion. The exhaust areas were the actual areas of each exhaust flow, and the thrust coefficients were referenced to the basic Model MA50-XCA 57-inch diameter reference area. The exhaust pressure,  $P_e$ , was the nozzle exit pressure established in earlier studies of boattail-nozzle optimization (see Section 2.3).

The boattail and base drag coefficients are equivalent to the expression:

$$C_D = \frac{A_{max}}{A_R} \int_{A_{min}}^{A_{max}} c_p dA$$

Values of boattail pressure coefficients were taken from Reference 12, while base pressure coefficients were taken from Reference 13.

\*Symbol definitions at end of section.

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

MAY 29 2015

THE  
*Marquardt*  
CORPORATION  
VAN NUYS, CALIFORNIA

REPORT 58

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

### Annular, Forced Convection Nozzle

The configuration of this nozzle is shown in Figure 35. This system used the basic optimized primary nozzle contour. The secondary cooling flow was passed through a constant flow area annular passage formed by the primary nozzle wall and an outer shell. The airframe cooling flow was allowed to flow between the secondary outer wall and the airframe boattail. To reduce drag, pressures in both passages were maintained high by choking these flows near the exit of the exhaust with the dual-annular exhaust nozzle, which also permitted supersonic expansion to the primary nozzle exit pressure. Further, this arrangement eliminated the base drag consideration.

The ideal thrust of the primary nozzle was obtained by assuming a one-dimensional isentropic expansion of the actual nozzle flow from the upstream total to the exhaust pressure, or simply:

$$F_{P_i} = \frac{W_P}{g} V_{ep}$$

The actual nozzle thrust was computed from the expression:

$$F_P = \frac{W_P}{g} C_{VP} V_{eP}$$

where  $C_{VP} = 0.983$ , the experimentally determined coefficient presented in Section 3.8.2 of this report.

The secondary exhaust nozzle thrust coefficient was evaluated by determining the pressure drop in the secondary annulus and computing the actual thrusts of the secondary exhaust nozzle. The pressure drop was computed using the computer program Rlta described earlier in this section. A velocity coefficient of 96 percent was assumed for the secondary exhaust nozzle, and the exhaust velocity of both the actual and ideal cases was computed from the actual exhaust total temperature. The secondary nozzle exhaust flow was axial to minimize the divergence loss of this flow.

### Tubular, Forced Convection Nozzle

The exhaust system of the tubular walled nozzle is shown in Figure 36. The primary nozzle thrust coefficient was assumed to be equal to that of the full annular nozzle, because any additional loss would be the result of increased wall friction. Evaluation of the phenomena of boundary layer growth

~~SECRET RESTRICTED DATA~~

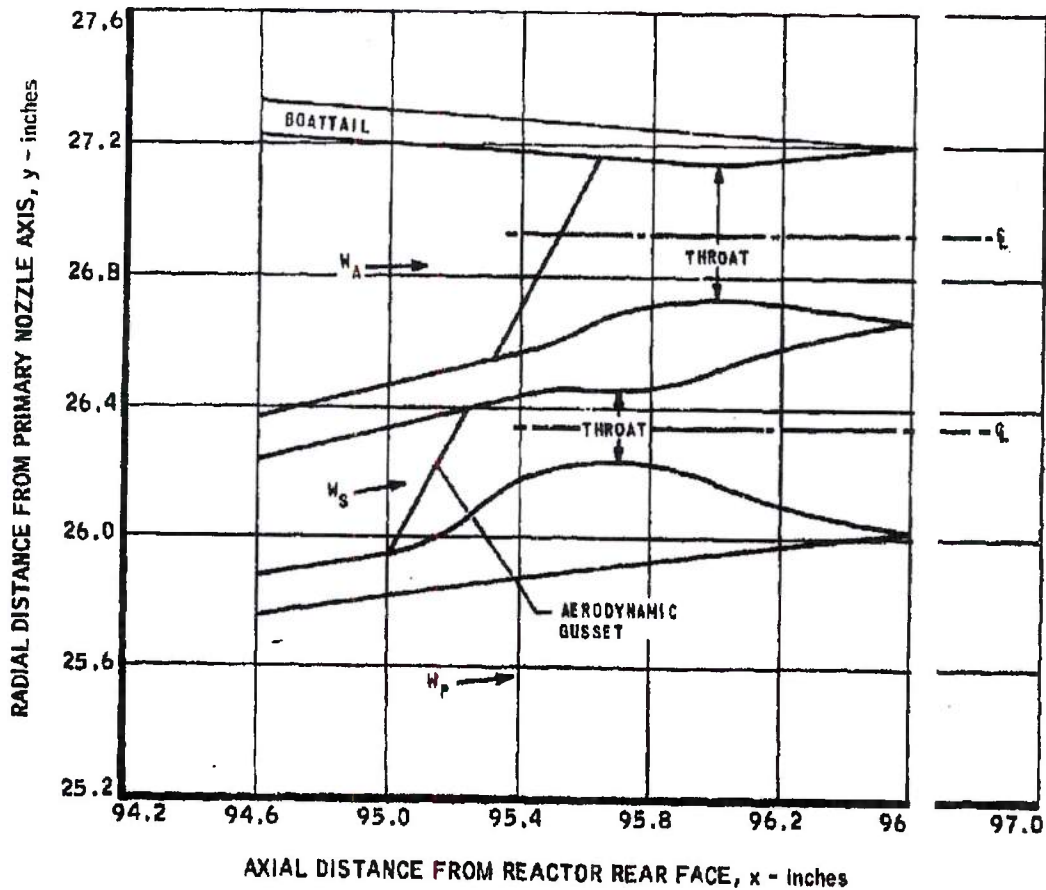
~~ATOMIC ENERGY ACT OF 1954~~

MAY 29 2015  
~~CONFIDENTIAL~~

THE Marguardt  
 CORPORATION  
 VAN NUYS, CALIFORNIA

PORT 5876

# DIAGRAM OF ANNULAR, FORCED CONVECTION NOZZLE EXHAUST SYSTEM



MAC AGO

N22E637 ~~CONFIDENTIAL~~

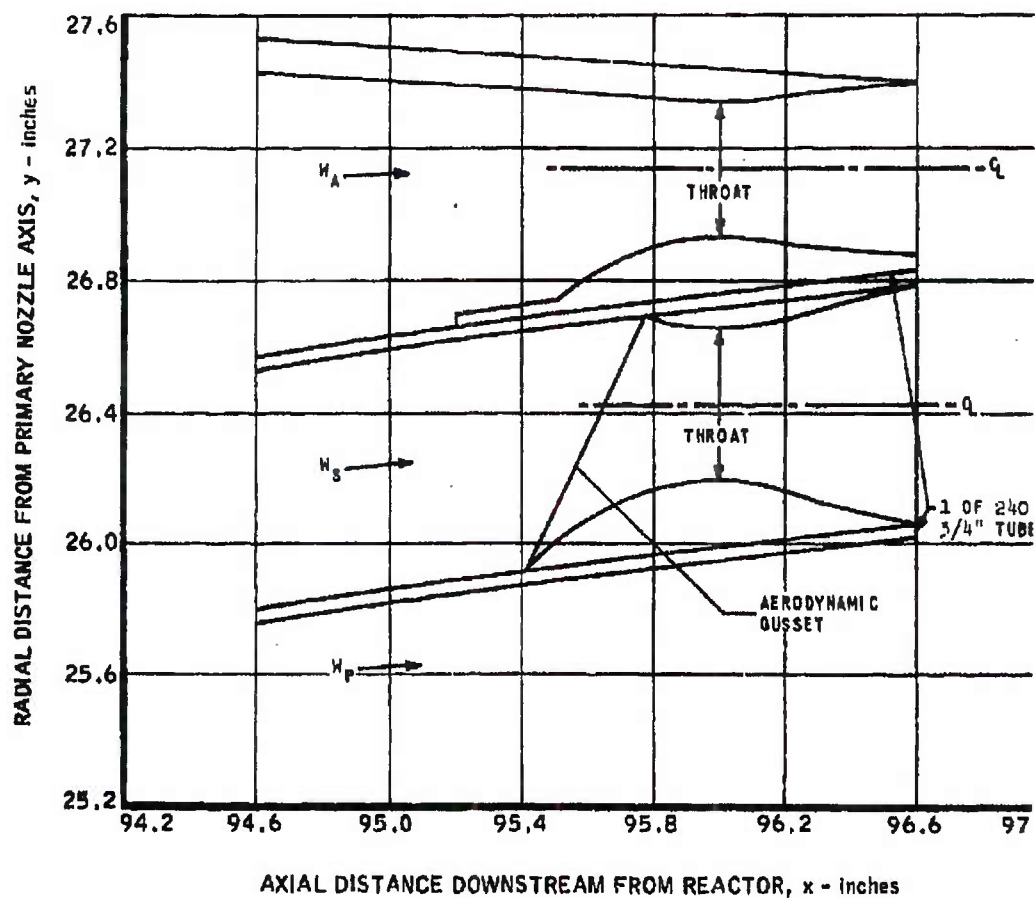
MAY 29 2015

THE *Marquardt*  
 CORPORATION  
 VAN NUYS, CALIFORNIA

REPORT 58

~~CONFIDENTIAL~~

# DIAGRAM OF TUBULAR, FORCED CONVECTION NOZZLE EXHAUST SYSTEM



MAC 1001

N22E368

~~CONFIDENTIAL~~

-60-

FIGURE E 36





~~SECRET RESTRICTED DATA~~

REF 5876

~~ATOMIC ENERGY ACT OF 1954~~

over the tubular wall to define a momentum loss that could be weighed against the boundary layer momentum loss of the full annular nozzle would be excessively ambitious at this time. The analysis of the secondary flow was very similar to the full annular case, the major differences being that there was an increased pressure drop through the tubes and that each of the 240 tubes incorporated a convergent-divergent nozzle at the exit.

### Ejector Nozzle

The exhaust details of the ejector nozzle are shown in Figure 37. The analysis of the ejector nozzle was complicated by the supersonic mixing of the primary and secondary flows. This situation was handled by assuming each flow remained isolated from the other, but both were penalized by friction with each other. Because the primary stream properties under the above assumption were identical with the full annular nozzle primary flow, the maximum velocity difference between the primary stream and the cooling flows was assumed that the friction loss between primary and cooling flows was a function of control volume causing the friction. A theoretical solution of the boundary layer loss of the primary flow in the annular nozzle provided a suitable reference. Here the maximum velocity difference (stream to wall) was equal to the velocity of the edge of the boundary layer at the nozzle exit. With the ejector nozzle, the maximum velocity difference occurred where the secondary passage ended. Because with friction, the individual stream velocities would tend to converge, the maximum velocity difference was merely the difference in velocity between the primary stream and the secondary stream. Because the primary stream was assumed to slide within the sheath of the secondary stream, the maximum velocity difference was merely the difference in velocity between the two streams at the above location. With these assumptions it was possible to write:

$$\Delta F_{\text{ejector}} = \Delta F_{\text{forced convection}} \frac{\text{maximum } \Delta V_{\text{ejector}}}{\text{maximum } \Delta V_{\text{forced convection}}}$$

where  $\Delta F$  was the momentum loss resulting from friction between the primary and secondary streams.

The actual thrust of the secondary flow was computed by using the total pressure at the secondary passage exit and the nozzle exit pressure, and by subtracting one half of the  $\Delta F_{\text{ejector}}$  term above. The pressure drop of the secondary passage upstream of the secondary unit was computed using the program Rita. Because the total pressure of the secondary flow was evaluated through the sonic region to the secondary flow passage exit, the nozzle velocity coefficient was assumed to be unity. However, this secondary exhaust flow was

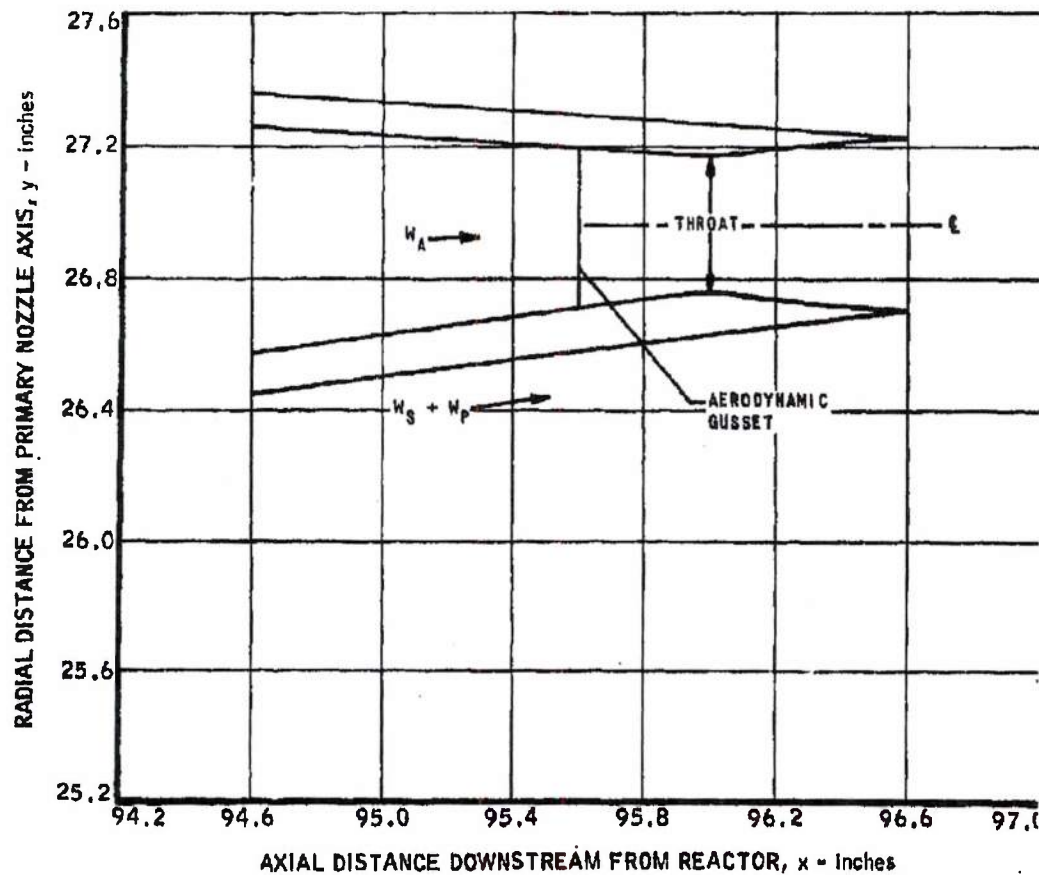
MAC 1403

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

~~CONFIDENTIAL~~

# DIAGRAM OF EJECTOR NOZZLE EXHAUST SYSTEM





~~SECRET RESTRICTED DATA~~

BT 5876

~~ATOMIC ENERGY ACT OF 1954~~

penalized for divergence loss at the exhaust nozzle exit. Both the actual and ideal exhaust velocities were evaluated at the actual total temperature at the exit of the secondary passage.

To compute the actual thrust of the primary flow, the above analysis of the secondary flow was used in conjunction with reliable experimental data from a model of the specific configuration under analysis. The two quantities were related by:

$$C_{VPS} = \frac{W_P C_{VP} V_{ePi} + W_S C_{VS} V_{eSi}}{W_P V_{ePi} + W_S V_{eSi}}$$

The combined coefficient,  $C_{VPS}$ , was presented in Section 3.8.2 of this report and obtained experimentally. The coefficient,  $C_{VS}$ , was the ratio of actual to ideal thrust of the secondary flow. With these coefficients, it was possible to solve for the nozzle thrust coefficient,  $C_{VP}$ , of the primary flow, which would include friction, divergence, and interaction losses.

#### Radiation Cooled Nozzle

The exhaust configuration of this nozzle is shown in Figure 38. With this configuration, the secondary cooling flow was mixed with the primary flow at the reactor exhaust. Complete mixing was assumed upstream of the nozzle, and both the primary and secondary flows were expanded through the single (somewhat larger) "primary" nozzle. Divergence and friction losses were considered as in the case of the annular nozzle.

#### Nozzle Flow Conditions

##### Primary Flow

The primary flow rate for all configurations analyzed was 1577 lbs/sec. The total pressure at the nozzle inlet was 31,000 psfa, and the total temperature was 2060°F. Both were assumed constant throughout the expansion of the isentropic core to the optimized nozzle exhaust pressure of 140 psfa.

##### Secondary Flow

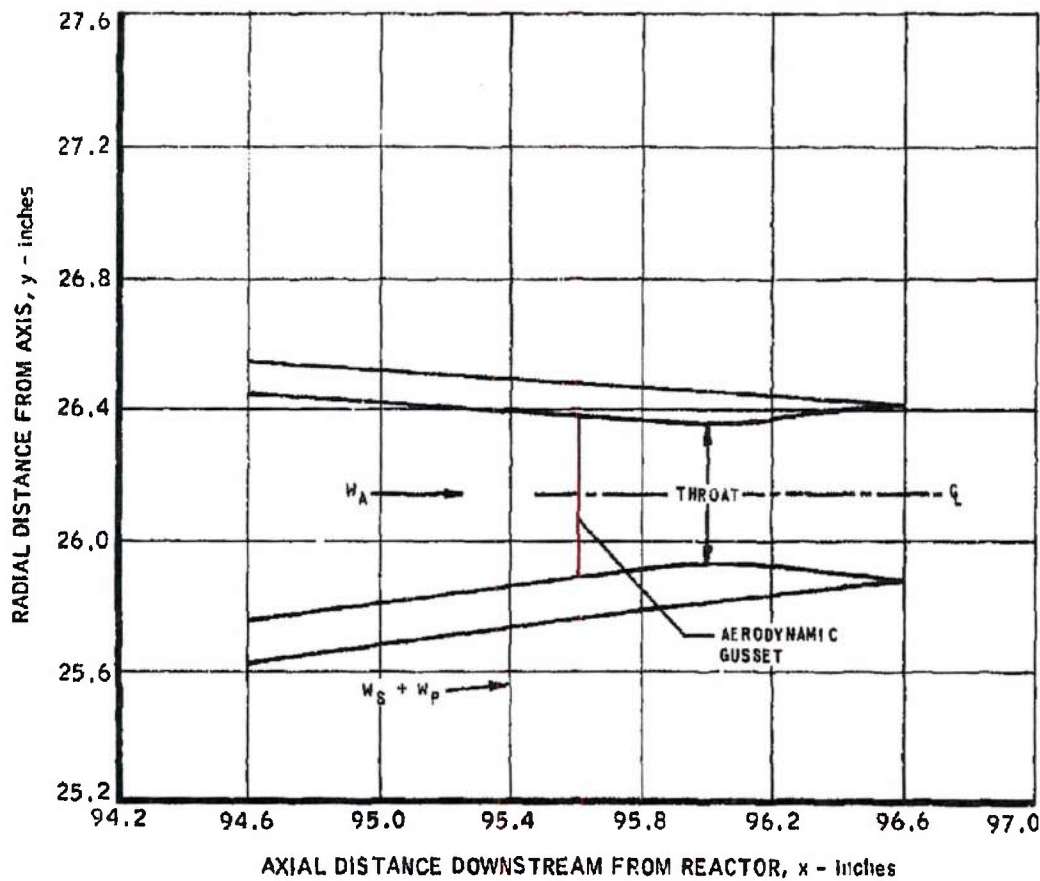
The secondary flow rate for all configurations considered was 100 lbs/sec. The total pressure at the reactor side support exhaust was taken to be 36,700 psfa for all cases except for the radiation cooled nozzle. The total temperature at this axial station was 1060°F. Total pressure drop and total

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

~~CONFIDENTIAL~~

DIAGRAM OF RADIATION COOLED NOZZLE EXHAUST SYSTEM



~~CONFIDENTIAL~~





~~SECRET RESTRICTED DATA~~

SI 5876

~~ATOMIC ENERGY ACT OF 1954~~

temperature rise resulted from friction and heat transfer to the secondary flow. The secondary flow of all configurations evaluated was expanded to 580 psfa.

#### Airframe Cooling Flow

The aerothermodynamics contractor furnished the data for this flow. The weight flow was 42.3 lbs/sec, and total pressure at the ejector exit station was 7200 psfa. The flow exhaust was choked with 70.0 square inches of flow area. Solution of the continuity equation defined the total temperature as 1280°F. To avoid the inconsistency of omitting one of the afterbody flows in the exhaust system analysis, the thrust coefficient of the airframe cooling flow was computed. For this computation, total temperature was assumed constant, and a 2 percent total pressure drop within the boattail was assumed. This flow was also expanded to 1680 psfa.

#### Results

The primary nozzle thrust coefficient,  $C_{v_p}$ , was assumed identical for the annular and the tubular configurations and was established as 0.983. The thrust coefficient of the primary flow with the ejector configuration was determined to be 0.9825. This reflected an interaction loss of approximately 0.05 percent from the basic forced convection configuration.

The thrust coefficients, total pressure drop, and total temperature rise of the secondary flow expansion, where appropriate, were as follows:

	$C_{v_s}$	$P_T$ (%)	$T_T$ (°F)
Annular Nozzle	0.929	-14.1	+ 98
Tubular Nozzle	0.929	-21.8	+180
Ejector Nozzle	0.953	-11.4	+ 63

The decrease in thrust coefficient resulting from an increase in pressure drop was compensated, to a degree, by an increase in total temperature

The primary and secondary flows of the radiation cooled nozzle were mixed prior to entering the nozzle. This condition resulted in a total temperature of the mixture of 1990°F, or a change of 70°F, which would have little effect on friction losses and divergent losses of the basic primary nozzle. Thus the nozzle thrust coefficient for the combined primary and secondary flows of this configuration was also 0.983.

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~



~~SECRET RESTRICTED DATA~~

REPORT 58

~~ATOMIC ENERGY ACT OF 1954~~

The boattail drag coefficient,  $C_{D_{BT}}$ , was determined to be -0.018 or the optimized nozzle-boattail configuration. Small variations in boattail ex area between configurations were assumed insignificant. The tubular nozzle inherently had a section of base area and a resulting base drag coefficient,  $C_{D_b}$ , of -0.0056.

The net thrust coefficient of the various flows was as follows:

	$C_{TP}$	$C_{TS}$	$C_{TA}$
Annular Nozzle	0.1983	-0.0007	-0.0028
Tubular Nozzle	0.1983	-0.0020	-0.0028
Ejector Nozzle	0.1977	-0.0004	-0.0028
Radiation Cooled Nozzle	0.1957	- -	-0.0028

The net thrust coefficients of the various installed exhaust system evaluated were as follows:

	$C_{TN}$
Annular Nozzle	0.1768
Tubular Nozzle	0.1699
Ejector Nozzle	0.1765
Radiation Cooled Nozzle	0.1749

The above net thrust coefficients give an approximate comparison of the four general configurations considered. The annular and the ejector configurations appear slightly favorable in the initial analysis. It is evident that the tubular nozzle was penalized by higher pressure drop and base drag. The radiation cooled nozzle coefficient was slightly low as a result of the inefficient mixing upstream from the nozzle. While some optimization is evident in the above configurations, they still are only arbitrary configurations, analyzed for general comparison. They cannot be considered sufficiently sophisticated to permit selection or elimination. Prior to final selection, the favored configuration will be mechanically optimized to assure efficient fabrication.

The particular exhaust system selected for the Model MA50-XCA engine should be the one that yields superior performance and can be satisfactorily cooled. The superior performance should occur at design conditions, but it

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~



5876

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

cooling requirements must be fulfilled at the most extreme heating condition, which will be at off-design conditions. The performance of the primary nozzle system has been optimized with regard to the boattail drag, and the cooling system is currently being optimized. To fairly evaluate each of the cooling schemes under consideration, each should be optimized with respect to temperature and mechanical design. The performance of each optimum cooling configuration should then be evaluated for selection of one optimum configuration.

Generally, the nozzle cooling flow conveniently available has been established by reactor and airframe cooling requirements. Further geometric variations can control, to a degree, the effectiveness of the cooling flow. By increasing the local Mach number of the cooling flow, the nozzle wall temperature may be reduced, but the drag of the cooling flow will increase because of increased pressure drop. To minimize this drag, the geometric configuration that will yield the maximum acceptable metal wall temperature will be the one that will have the lowest pressure drop. When this configuration has been established, the cooling system analysis will continue with optimization of nozzle performance by optimizing nozzle cooling flow.

#### Nomenclature

A	=	Area
C <sub>D</sub>	=	Drag coefficient
C <sub>T</sub>	=	Thrust coefficient
C <sub>V</sub>	=	Velocity coefficient (also, nozzle thrust coefficient)
F	=	Thrust
M	=	Mach number
P	=	Pressure
T	=	Temperature
V	=	Velocity
W	=	Weight flow
g	=	Acceleration due to gravity
c <sub>p</sub>	=	Local pressure coefficient
γ	=	Ratio of specific heats
θ	=	Angle with nozzle axis

#### Subscripts

A	=	Airframe cooling flow
BT	=	Afterbody boattail
N	=	Net (or installed)
P	=	Primary flow

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

~~SECRET RESTRICTED DATA~~

REPORT 587

~~ATOMIC ENERGY ACT OF 1954~~

Subscripts (Continued)

R = Reactor  
S = Secondary flow  
T = Stagnation conditions  
b = Afterbody base  
e = Exit (or exhaust)  
i = Ideal  
ic = Isentropic core  
max = Maximum quantity of a considered interval  
min = Minimum quantity of a considered interval  
o = Free stream conditions  
pr = Within limits of pressure ratio  
w = Nozzle wall

3.3 ENGINE PERFORMANCE SUMMARY (PERFORMANCE BULLETIN NO. 4)\*

3.3.1 Introduction

The purpose of the performance bulletin is to disperse quickly to interested parties The Marquardt Corporation's prediction of the performance of a nuclear ramjet propulsion system incorporating the Tory IIC type reactor. The first two performance bulletins presented performance of the Marquardt Model MA50-XCA propulsion system incorporating the basic Tory IIC reactor. Performance Bulletin No. 3, describing the Model MA50-XDA propulsion system, departed from the basic Tory IIC reactor design in that the reactor length was decreased and the diameter was increased.

This fourth performance bulletin represents Phase II of performance prediction, wherein reasonable advancements over present Tory IIC technology are studied. LRL has concurred in the basic feasibility of each of the items discussed herein.

\*Dated 31 December 1961.

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHIS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~





~~SECRET RESTRICTED DATA~~

INT 5876

ATOMIC ENERGY ACT OF 1954

In general, these performance bulletins follow the format set forth in Reference 14. (See Item IV of the section entitled "Reports and Data Requirements.") Each bulletin supplements rather than replaces preceding bulletins.

### 3.3.2 Summary

With the publication of the first three performance bulletins, Phase I of the 1961 propulsion system performance prediction ended. This phase has been devoted to propulsion systems incorporating present Tory IIC technology. Design point performance, off-design characteristics, and diameter scaling effects were presented along with inlet pressure recovery and reactor wall temperature influence coefficients. Performance Bulletins No. 1 and No. 2 summarize Marquardt's prediction of performance of the Model MA50-XCA system using the basic Tory IIC reactor.

Using the engine size scaling information contained in the bulletins, the aerothermodynamic contractor established that the basic reactor diameter would have to increase from the nominal Tory IIC size of 57.0 to about 63.0 inches to accomplish the ADO No. 11 mission. In order to improve aerothermodynamic performance as well as to reduce reactor weight, the forward reflector thickness was decreased by 4 inches, the fueled length of the core was decreased by approximately 4 inches, and reactor diameter was increased from 57.0 to 63.0 inches. This propulsion system, designated the MA50-XDA, provides the thrust necessary to perform the ADO No. 11 mission. This system was reported in Performance Bulletin No. 3.

Phase II of this year's effort, discussed in this fourth bulletin, deals with the Model MA50-XCA system performance effects associated with realistic modifications to the Tory IIC reactor geometry and technology. Geometric modifications include:

- (1) Optimization of the reactor length-to-diameter ratio,  $L/D_0$  for constant  $D_0$ .
- (2) An increase in the diameter of the base-block billet, which allows a reduction in the number of tie rods.
- (3) A change in fuel region void fraction by increasing the fuel element tube diameter.

Technological modifications include:

- (1) Modifying the core power profile to maintain a constant elastic thermal stress of 15,000 psi and/or a maximum reactor wall temperature of 2500°F.

~~SECRET RESTRICTED DATA~~

ATOMIC ENERGY ACT OF 1954

~~SECRET RESTRICTED DATA~~

REPORT 587

~~ATOMIC ENERGY ACT OF 1954~~

- (2) Modifying the core power profile to maintain a constant elastic thermal stress of 18,000 psi and/or a maximum reactor wall temperature of 2500° F. This higher stress limit study is prompted by the results achieved with the Tory IIA reactor, which operate successfully at power levels higher than design point.
- (3) Reducing the amount of air flow to the tie rods, until a limiting temperature of 1650° F is achieved.

Finally, operating envelopes have been established for the basic Mod MA50-XCA propulsion system.

### 3.3.3 Scope

The goal of the Pluto performance studies conducted to date has been the incorporation of the Tory IIC type reactor in a reliable nuclear ramjet propulsion system capable of performing Air Force mission requirements. Performance Bulletin No. 4 differs from previous studies in that it is based on important extensions of present Tory IIC technology. The performance gains achieved are believed realistic for a flight type propulsion system.

The design point for the Marquardt nuclear ramjet propulsion system is Mach 2.8, at a pressure altitude of 1,000 feet, under ANA Hot Day temperature conditions. The maximum reactor wall temperature is 2500° F.

This performance bulletin includes the following:

### Design

A brief description of the Model MA50-XCA engine is included with drawings, weights and center of gravity, dimensional information for mounting points, and an over-all envelope including basic airframe dimensions. A major modification of the reactor lateral support structure has been incorporated into the propulsion system design. The pressure vessel has been eliminated from the design, with the inner airframe skin assuming the function previously performed by this component. The female track is now an integral part of the expansion shell and the male rail is still fastened to the airframe structure as previously shown. The tangentially aligned Belleville spring stacks and the track and rail structure are integrated into a compact annulus. This system reduces the airframe outer mold line diameter by 4.375 inches.

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

~~SECRET RESTRICTED DATA~~

RT 5876

ATOMIC ENERGY ACT OF 1954

### Heat Rejection

Heat rejection rates for the Model MA50-XDA propulsion system of Reference 4 are presented for design point conditions.

### Performance

Model MA50-XCA propulsion system design point information (Reference 3) is presented in tabular form to be used as a basis for comparison with the following studies:

- (1) The effects of reducing the front reflector 4 inches and the aft fueled core 4.1 inches.
- (2) The effects of changing the core power profile to yield a constant elastic thermal stress of 15,000 psi and/or a maximum wall temperature of 2500°F. For this study, the properties of thermal conductivity, modulus of elasticity, and the coefficient of expansion were considered to be temperature dependent.
- (3) The effects of changing the core power profile to yield a constant elastic thermal stress of 18,000 psi and/or a maximum wall temperature of 2500°F.
- (4) The effects on performance when the basic base-block billet size is increased to 9 inches from the present 5 inches. For this case the number of tie tubes has been reduced by the ratio 9:1, and the volume originally occupied is replaced with fueled core tubes.
- (5) The effects of reducing the tie rod airflow until the tie rod reaches an equilibrium temperature of 1650°F.
- (6) The effects of increasing the core void fraction by increasing the fueled tube diameter from 0.227 to 0.230 inches.

### Operating Envelopes

Operating envelopes for the basic Model MA50-XCA propulsion system are described for the ANA Hot and Cold Days and the ICAO standard Day temperatures. High speed operation is limited either by a ram air total temperature of 1070°F or a diffuser duct pressure of 420 psia.

~~SECRET RESTRICTED DATA~~

ATOMIC ENERGY ACT OF 1954

~~SECRET RESTRICTED DATA~~

REPORT 5876

ATOMIC ENERGY ACT OF 1954

### 3.3.4 Definitions

Net Jet Thrust - Net jet thrust is defined as the sum of the change in momentum of the mass flow through the engine and the pressure differential acting upon the exit area, as shown in the following equation:

$$F_{nj} = \left( \frac{W_6 V_6 - W_o V_o}{g} \right) + (P_6 - P_o) A_6$$

The exit area ( $A_6$ ) used in this equation corresponds to a fully expanded nozzle at the design point. The momentum of the air used to cool both the side support system inside the pressure vessel and the exit nozzle is included in the net jet thrust.

Net Jet Thrust Coefficient - Net jet thrust coefficient is defined as the net jet thrust divided by the incompressible dynamic pressure and by the reference area of the reactor in square feet as shown in the following equation:

$$C_{F_{nj}} = \frac{F_{nj}}{1/2 \rho_o V_o^2 A_R}$$

The reference area used in this bulletin for the propulsion system, is 17.72 square feet.

Engine Installation Drag - Engine installation drag is defined as the sum of the inlet supersonic spillage drag, inlet bleed drag, and the engine bypass drag necessary for engine matching.

By agreement, the airframe contractor will take into account:

- (1) The inlet installed drag other than the supersonic spillage term such as the cowl drag, the diverter drag, and the inlet base drag;
- (2) The drag attributed to air bleed from inlet duct for power actuation, air conditioning, or cooling of gamma-neutron shielding; and
- (3) Nozzle base and boattail drag

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

ATOMIC ENERGY ACT OF 1954



~~SECRET RESTRICTED DATA~~

5876

~~ATOMIC ENERGY ACT OF 1954~~

The drag of these items must be included to obtain the actual installed thrust.

Engine Installation Drag Coefficient - Engine installation drag coefficient is defined as the engine installation drag of the previous paragraph divided by the incompressible dynamic pressure and the reference area of the reactor.

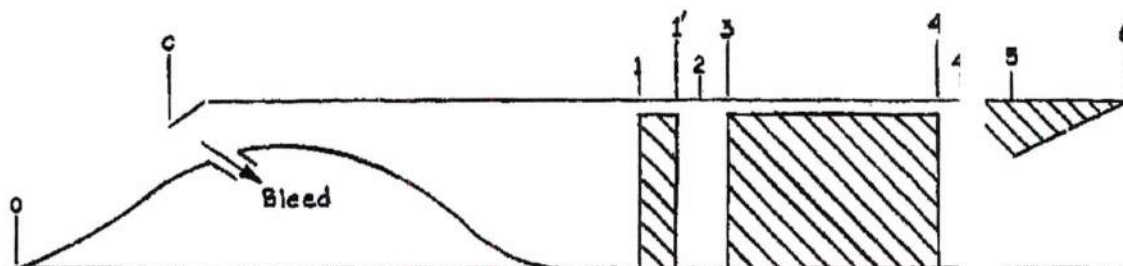
Installed Net Thrust - The installed net thrust is equal to the net jet thrust minus the engine installation drag. As pointed out in a previous paragraph, only a portion of the engine installation drag is included herein.

Installed Net Thrust Coefficient - Engine installed net thrust coefficient is defined as the engine installed thrust divided by the incompressible dynamic pressure and the reference area of the reactor.

Symbols - The following symbols and subscripts are used:

	<u>Description</u>	<u>Unit</u>
A	Cross-sectional area	sq ft
C	Coefficient	-
F	Thrust	lb
M	Mach number	-
P	Pressure	psf
T	Temperature	°Rankin
V	Velocity	fps
W	Weight flow rate	pps
g	Gravitational acceleration, 32.17	ft/sec <sup>2</sup>

Subscripts - Subscripts shall be employed in accordance with the following station identification sketch and tabulation:



~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

-73-

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

REPORT 5: 6

~~ATOMIC ENERGY ACT OF 1954~~

Description

0	Free stream conditions
1	Forward face of reactor support grid
1'	Exit of reactor support grid
2	Plenum upstream from reactor face
3	Forward face of reactor
4	Exit of reactor
4'	Plenum downstream from reactor
5	Nozzle throat
6	Nozzle exit
c	Cowl lip
D	Drag
F	Thrust
j	Jet
n	Net
R	Reactor
s	Static
t	Total
w	Wall

3.3.5 Limitations

The performance of the basic Model MA50-XCA propulsion system is based on the component nuclear heat generation data of Reference 1. With minor exceptions, which are generally discussed in the respective areas, nuclear heat generation values for this performance bulletin were also taken from Reference 1. However, the reactor power profiles for the 15,000-psi and 18,000-psi elastic thermal stress studies were generated by Marquardt.

The following revisions were made to the basic Model MA50-XCA propulsion system:

- (1) Four inches of the reactor forward reflector have been removed and the nuclear heat generation in the remaining 6 inches has not been changed from that shown in Reference 1.
- (2) Four and one-tenth inches of material have been removed from the reactor aft core region, and the core power profile (as presented in Reference 1) has been terminated at this point.

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

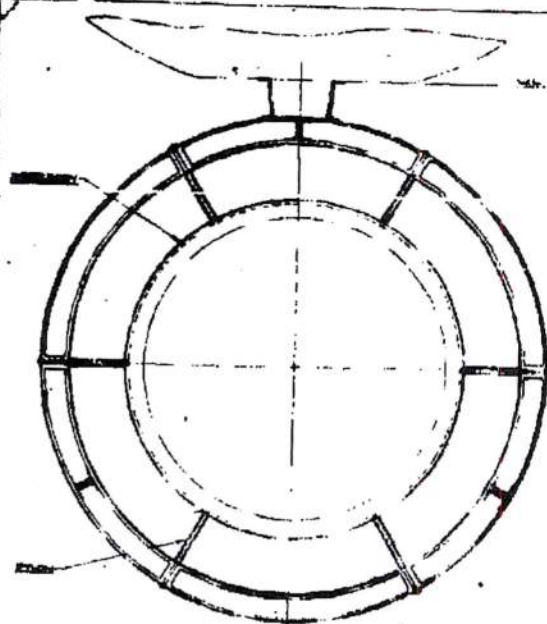


FIGURE 121

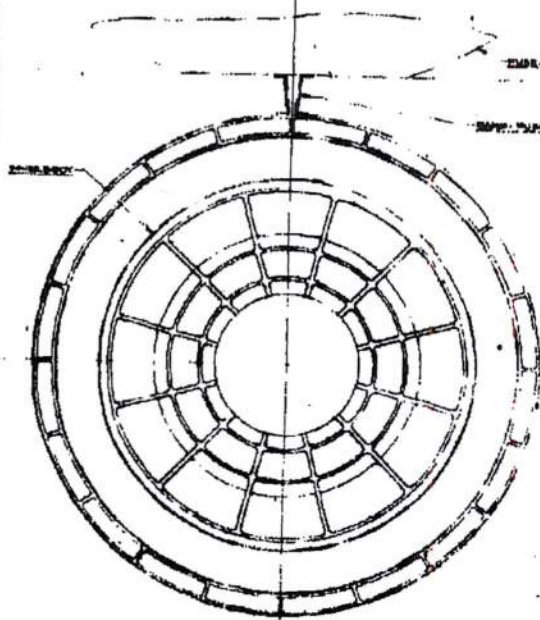


FIGURE 122

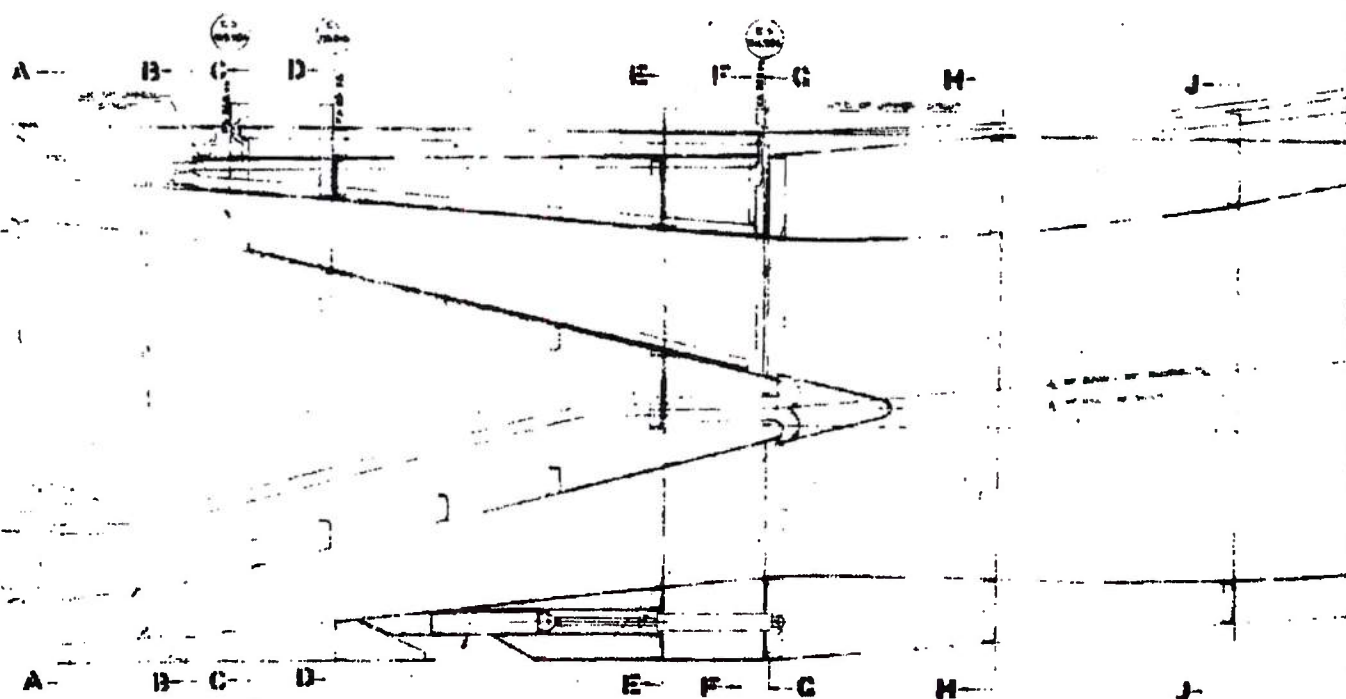
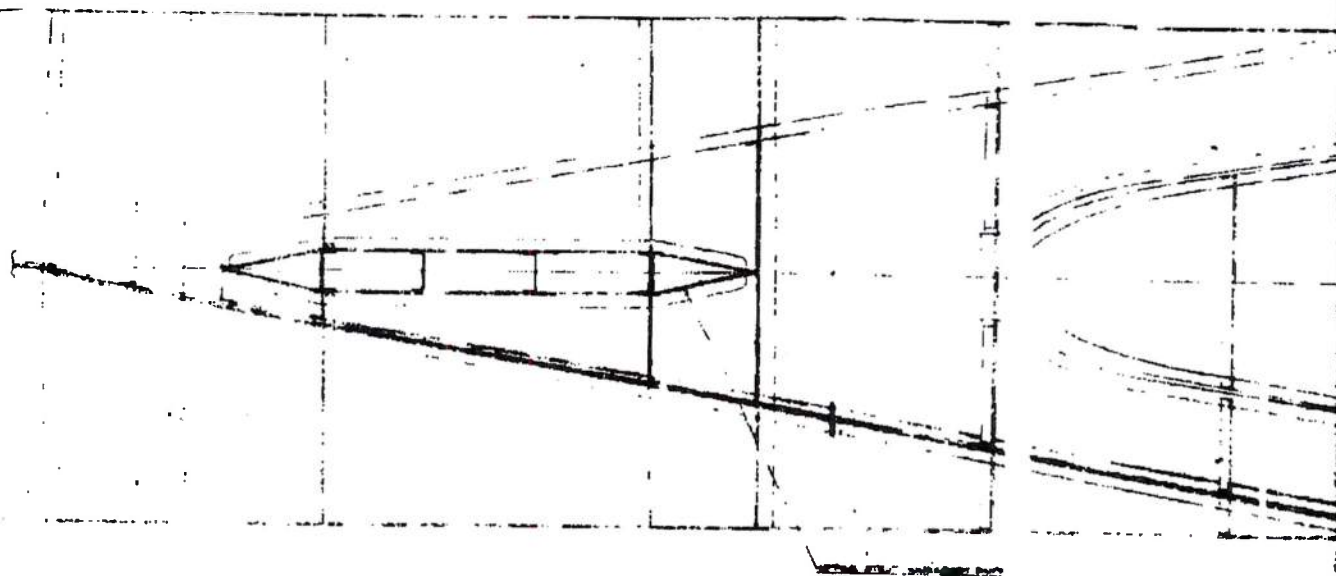
DECLASSIFIED IN FULL  
 Authority: EO 13526  
 Chief, Records & Declass Div, WHS  
 Date: MAY 29 2015

DECLASSIFIED IN FULL  
Authority: EO 12958

Authority: EO 13526

Chief, Records & Declass Div, WHIS

Date: MAY 29 2015



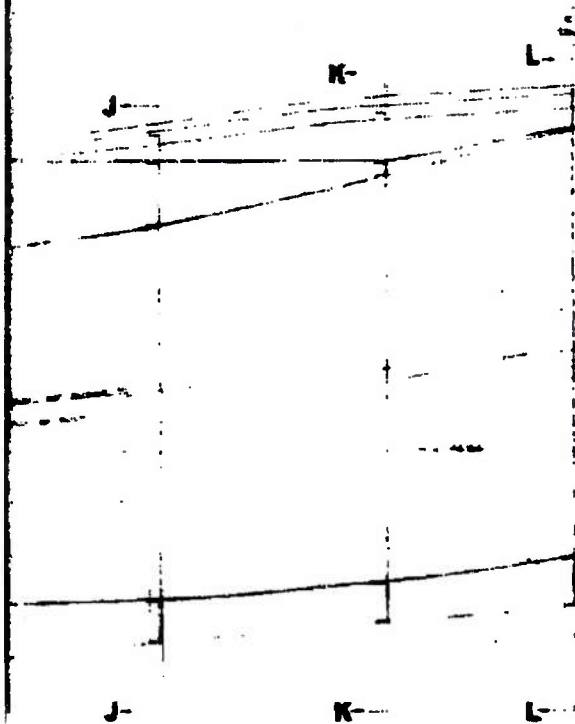
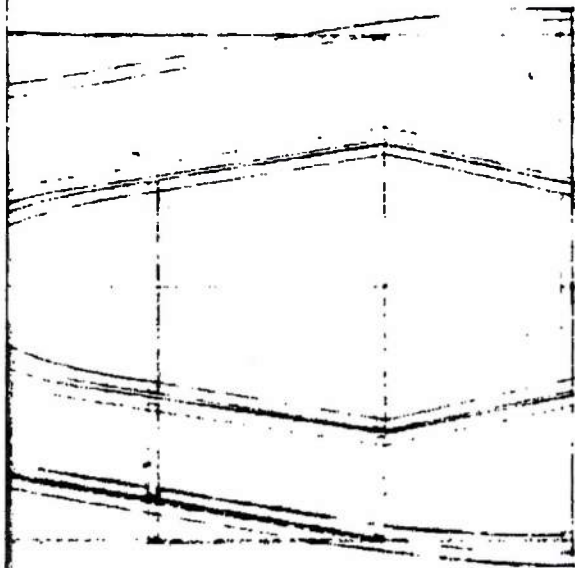
2017-2018

1. The first step is to identify the problem or question that needs to be answered. This involves understanding the context and the specific information required.

1. **Introduction**





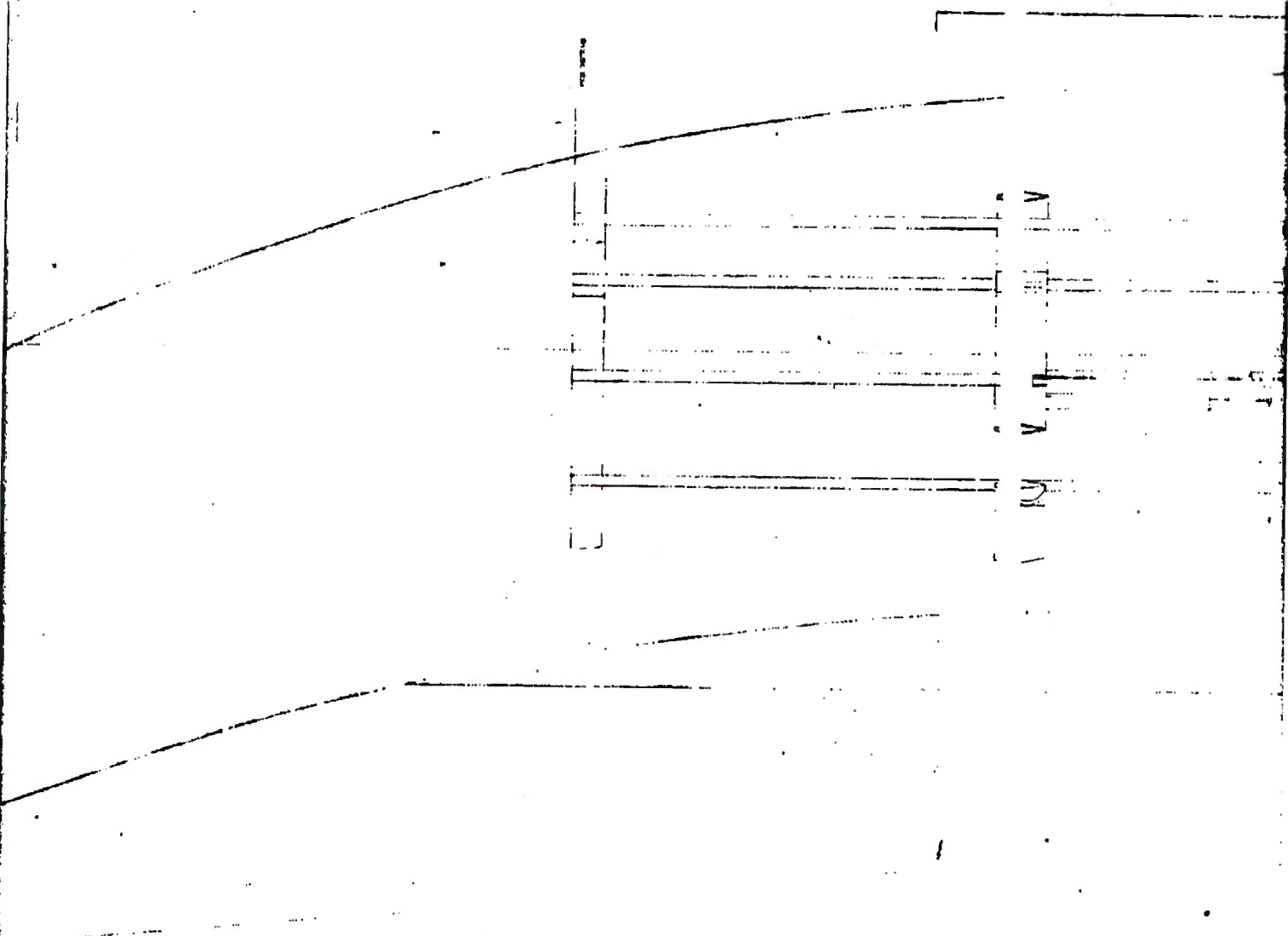


3

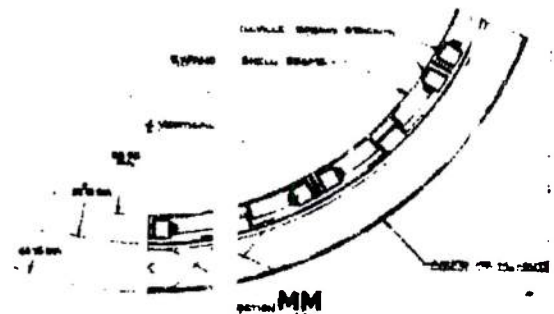
DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~GROUP 1 - DECLASSIFIED DATE~~  
~~12000 - 000000 - 000000~~

~~SECRET - RESTRICTED DATA~~  
~~ATOMIC ENERGY ACT OF 1954~~



DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHIS  
Date: MAY 29 2015



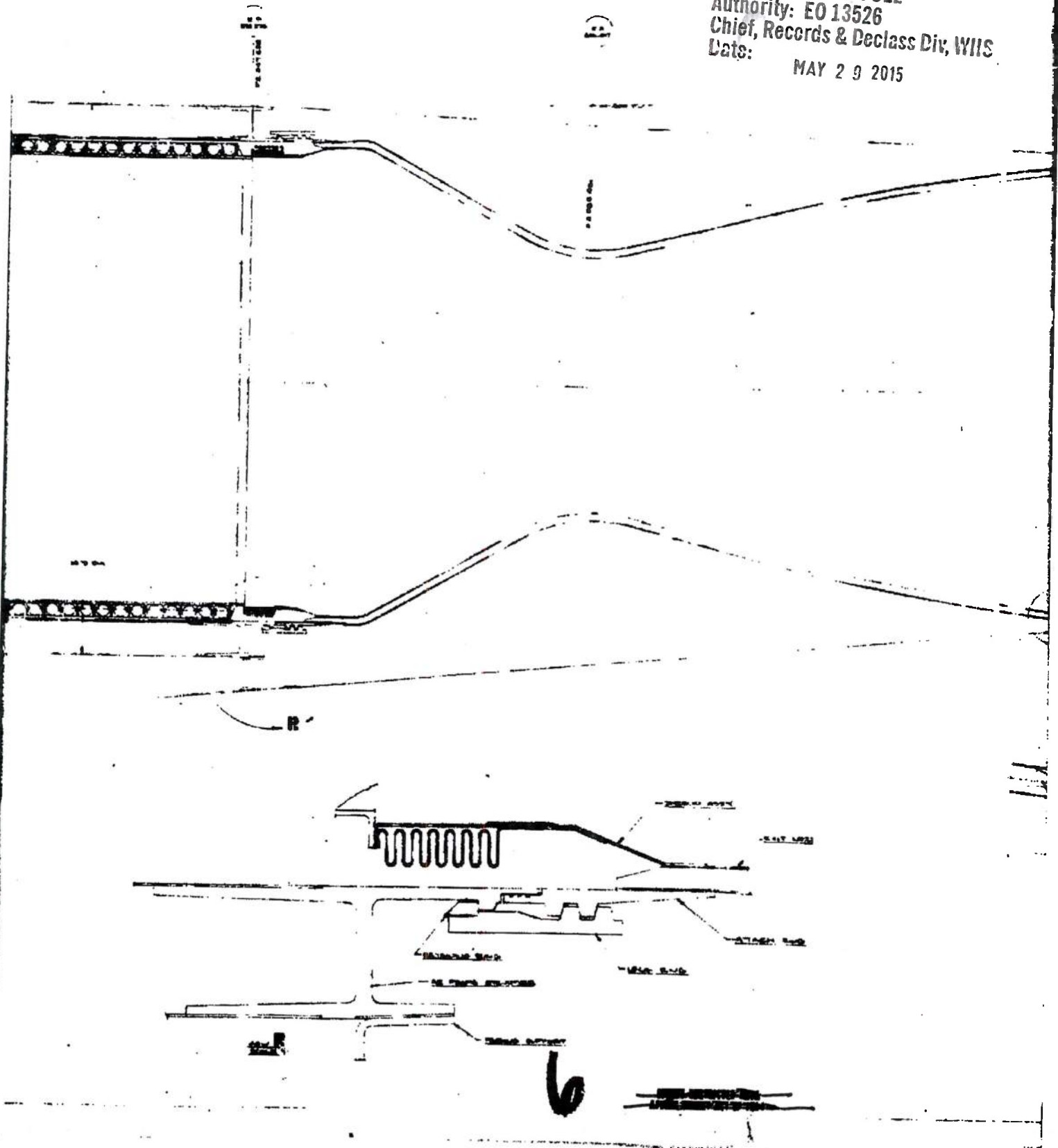
4

~~SECRET - RESTRICTED DATA~~  
~~ATOMIC ENERGY ACT OF 1954~~



RECEIVED 10/10/15  
APR 10 1964

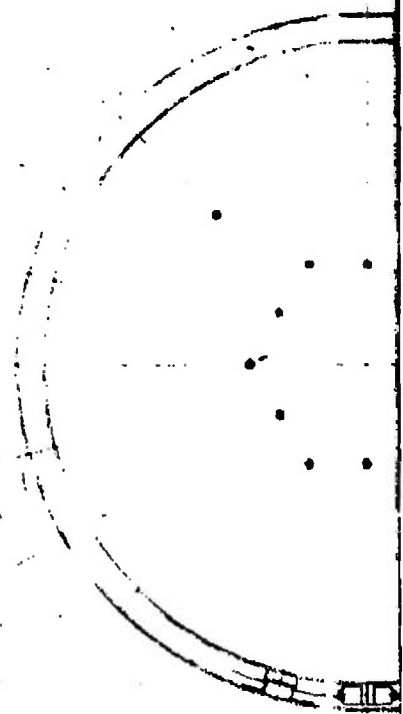
DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WILS  
Date: MAY 29 2015





~~SECRET - SECURITY INFORMATION~~  
~~EXCLUDED FROM AUTOMATIC DOWNGRADING AND DECLASSIFICATION~~

100-100000-100000



SECRET

100-100000-100000



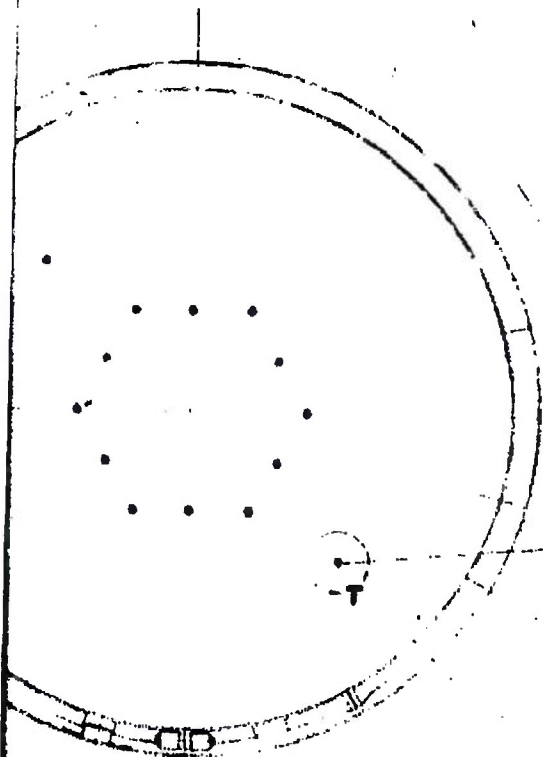
100-100000-100000

7

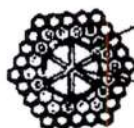
DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WIS  
Date: MAY 29 2015

~~SECRET - SECURITY INFORMATION~~  
~~EXCLUDED FROM AUTOMATIC DOWNGRADING AND DECLASSIFICATION~~

~~SECRET~~



SECTION PP



T  
PAGE 11

SECTION PP

SECTION PP

SECTION PP



4

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WIIS  
Date: MAY 29 2015

~~SECRET~~

1

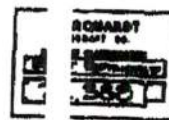
~~SECRET - SECURITY INFO~~  
~~NOFORN - SECURITY INFO~~

**Marquardt**  
CORPORATION

REPORT 5876

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

10



SECRET	REPORT NO.	5876
NOFORN	DATE	1968
CLASSIFICATION	EXEMPT FROM	DECLASSIFICATION
EXEMPT FROM	DECLASSIFICATION	DATE
EXEMPT FROM	DECLASSIFICATION	DATE

SECRET	REPORT NO.	5876
NOFORN	DATE	1968
CLASSIFICATION	EXEMPT FROM	DECLASSIFICATION
EXEMPT FROM	DECLASSIFICATION	DATE
EXEMPT FROM	DECLASSIFICATION	DATE

75- FIGURE 7



~~SECRET RESTRICTED DATA~~

POST 5876

~~ATOMIC ENERGY ACT OF 1954~~

The front grid void fraction and equivalent flow hydraulic diameter for all cases considered were generated by Marquardt as were the basic heat transfer and friction correlations.

### 3.3.6 Description of Nuclear Ramjet Propulsion System

#### General Description

The Model MA50-XCA nuclear ramjet propulsion system consists of a variable geometry supersonic inlet with a modified isentropic spike, a subsonic diffuser incorporating a variable area bypass, a nuclear reactor similar in construction to the Tory IIC reactor with integrated control system, and a convergent-divergent exit nozzle.

#### Engine Geometry

Basic details of this integrated propulsion system design are shown in Figure 39, (Marquardt Drawing Number X-81388). A brief description of the major components of the propulsion system follows:

The inlet, which is an underslung, axisymmetric, external internal compression type, has a translating centerbody spike with a maximum spike travel capability of 7 inches. The spike actuation mechanism is housed within the centerbody structure and is air operated. Air is supplied to the actuator through a slot located on the centerbody structure.

The subsonic diffuser duct structure, from aft of the supersonic inlet to the face of the reactor, is an integral part of the missile airframe structure. It will provide suitable fittings at the forward end for attachment of the inlet cowl and centerbody structure, and at the aft end for attachment to the inner airframe shell.

The nuclear reactor is composed of a series of individual elements that make up the core, the front, rear, and radial reflectors. The reactor is maintained in the form of a right circular cylinder by a spring-loaded expansion shell composed of 12 segments held together by a series of tangentially aligned stacks of Belleville springs. A series of axial tie tubes, which pass through the reactor, react and collect all aft directed loads through rear bearing plates and transfer them to a front support structure.

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

~~SECRET RESTRICTED DATA~~

ORT 5876

~~ATOMIC ENERGY ACT OF 1954~~

A track and rail system supports the reactor within the missile airframe and is designed for ease of installation. The pressure vessel has been eliminated from the design, the inner airframe shell assuming the function previously performed by this component. The female track is now an integral part of the expansion shell and the male rail is fastened to the airframe inner shell as previously shown. The tangentially aligned Belleville spring stacks and the track and rail structure are thus integrated. This system (shown in Figure 39) will permit ground handling equipment to lift and transfer the reactor assembly into the missile airframe. This design also compensates for differential thermal expansion between the reactor and airframe structure and will also transfer high radial inertia and vibration loads by tangential shear to the supporting airframe structure.

All axial loads imposed on the reactor are transferred to the airframe through a shear ring structure located at the station of the reactor front support structure.

The reactor control rod mechanisms are contained in an integrated package, which is mounted forward of the front support structure and housed within the inlet duct. Control rod actuators are mounted in the annulus between the diffuser duct and the missile airframe.

The convergent-divergent exit nozzle is an integrally brazed unit formed from a series of longitudinal tubes shaped to the nozzle contour and capped with a spiral-wound wire. Nozzle cooling is provided by routing air through the side support structure and then through the longitudinal tubes. The exit nozzle is cantilevered from the inner airframe shell near the rear face of the reactor and is attached by a threaded lock ring.

#### Weight and Center of Gravity for Engine Components

A preliminary weight breakdown for the flight type reactor (Model MA50-XCA) has been estimated, and the results are presented in Table 5.

Based upon the reactor weights of Table 5, calculations indicate that the propulsion system components have approximate weights and center of gravity (CG) locations as shown below. Station locations (Engine Station, ES) are used to indicate CG locations with respect to the over-all propulsion system.

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

~~SECRET RESTRICTED DATA~~

REF. 5876

~~ATOMIC ENERGY ACT OF 1954~~

	Weight (lbs)	Center of Gravity Location (Engine Station)
Inlet and spike	2,197	ES 182.6
Inlet duct	1,270	ES 405.6
Reactor controls	350	ES 445.9
Reactor assembly	12,830	ES 542.5
Exit nozzle	1,160	ES 604.8
TOTAL	17,806	ES 490.5

The center of gravity and station locations are also shown in Figure 39.

### 3.3.7 Heat Rejection

Heat rejection of the basic Model MA50-XCA propulsion system was reported in Reference 3. A similar analysis has been performed for the larger Model MA50-XDA propulsion system at design point conditions. With an airflow rate of 120 lb/sec in the side support compartment, the springs reached a maximum temperature of about 1360°F. The total cooling airflow rate inside the airframe structure was kept at 50 lb/sec. At this flow rate, the pressure shell reached a maximum temperature of 1280°F, the internal support member in the airframe reached a temperature of 1510°F, and the vehicle skin temperature was 1000°F. The total heat rejected by this system is about 3.8 Mw. A breakdown of this heat rejection is presented in Table 6. Heat generation rates in the side support system for this analysis were calculated by Marquardt.

### 3.3.8 Control System Characteristics and Requirements

These data are unchanged from Reference 4.

### 3.3.9 Engine Performance

A tabulation of aerothermodynamic values at design point conditions is presented in Table 7 to show the effects of each of the factors considered in this analysis. These effects can be compared with the basic Model MA50-XCA propulsion system. The various changes and the results are discussed in the order presented in the table.

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

MAC ACT

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

~~SECRET RESTRICTED DATA~~

5876

~~ATOMIC ENERGY ACT OF 1954~~

	Weight (lbs)	Center of Gravity Location (Engine Station)
Inlet and spike	2,197	ES 182.6
Inlet duct	1,270	ES 405.6
Reactor controls	350	ES 445.9
Reactor assembly	12,830	ES 542.5
Exit nozzle	1,160	ES 604.8
TOTAL	17,806	ES 490.5

The center of gravity and station locations are also shown in Figure 39.

### 3.3.7 Heat Rejection

Heat rejection of the basic Model MA50-XCA propulsion system was reported in Reference 3. A similar analysis has been performed for the larger Model MA50-XDA propulsion system at design point conditions. With an airflow rate of 120 lb/sec in the side support compartment, the springs reached a maximum temperature of about 1360°F. The total cooling airflow rate inside the airframe structure was kept at 50 lb/sec. At this flow rate, the pressure shell reached a maximum temperature of 1280°F, the internal support member in the airframe reached a temperature of 1510°F, and the vehicle skin temperature was 1000°F. The total heat rejected by this system is about 3.8 Mw. A breakdown of this heat rejection is presented in Table 6. Heat generation rates in the side support system for this analysis were calculated by Marquardt.

### 3.3.8 Control System Characteristics and Requirements

These data are unchanged from Reference 4.

### 3.3.9 Engine Performance

A tabulation of aerothermodynamic values at design point conditions is presented in Table 7 to show the effects of each of the factors considered in this analysis. These effects can be compared with the basic Model MA50 XCA propulsion system. The various changes and the results are discussed in the order presented in the table.

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~



~~SECRET RESTRICTED DATA~~

REPORT 58

~~ATOMIC ENERGY ACT OF 1954~~

TABLE 6

HEAT REJECTION OF MA50-XDA PROPULSION SYSTEM  
(Mach 2.8; ANA Hot Day; Altitude, 1,000 feet)

Item	Air Flow	Heat Rejection		
	(lb/sec)	(Btu/sec)	(Mw)	( )
Spring Compartment	120	2479	2.62	6.3
From Side Reflector	--	619	0.65	1.3
From Support Springs	--	1336	1.42	3.3
From Pressure Shell	--	524	0.55	1.7
Airframe	50	369	0.39	1.3
From Pressure Shell	--	78	0.08	.2
From Airframe Support	--	284	0.30	.9
From Vehicle Skin	--	7	0.01	.2
To Ambient From Vehicle Skin	--	728	0.77	2.4
TOTAL	--	3576	3.78	10.0

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

SECRET RESTRICTED DATA


  
 VAN NUYS, CALIFORNIA

PORT 5876

~~ATOMIC ENERGY ACT OF 1954~~

TABLE 7  
COMPARISON OF AEROTHERMODYNAMIC PARAMETERS  
FOR VARIOUS MODIFICATIONS TO BASIC MODEL MA50-XCA  
PROPULSION SYSTEM AT DESIGN POINT  
(MACH 2.8; ALTITUDE, 1,000 FT; ANA HOT DAY)

Parameter	(1) Basic Model MA50-XCA System (Ref. 3)	(2) Length- Optimized Model MA50-XCA System (Ref. 4)	(3) Temperature Dependent Thermal Stress Properties for 15,000 psi	(4) Temperature Dependent Thermal Stress Properties for 18,000 psi	(5) Increase of Base Block Billet Size	(6) Reduced Air Flow Per Tie Rod	(7) Increase of Reactor Void Fraction
Reactor Air Flow, $W_a$ , lb/sec	1580	1650	1580	1580	1580	1450	1580
Side Support Cooling Airflow, $W_{ac}$ , lb/sec	113	100	100	100	100	100	100
Core Tube Diameter, inches	0.227	0.227	0.227	0.227	0.227	0.227	0.230
Total Reactor Power, $Q$ , Mw	518	535	534	552	536	514	518
Reactor Exit (mixed) Total Temperature, $T_{t4}$ , °R	2520	2510	2560	2600	2560	2580	2520
Reactor Pressure Recovery, $P_{t4}/P_{t1}$	0.678	0.689	0.679	0.660	0.670	0.680	0.705
Reactor Length, $L_R$ , in.	627	54.6	62.7	62.7	62.7	62.7	62.7
Nozzle Throat Area, $A_5$ , ft <sup>2</sup>	4.94	5.08	--	--	--	--	--
Nozzle Exit Area, $A_6$ , ft <sup>2</sup>	12.7	13.2	--	--	--	--	--
Cowl Area, $A_c$ , ft <sup>2</sup>	7.97	8.25	--	--	--	--	--
Thrust Coefficient, $C_F$	0.200	0.206	0.205	0.210	0.205	0.201	0.202
Thrust, $F$ , (Full Expansion), lb	39,700	40,900	40,700	41,700	40,700	39,900	40,100

SECRET RESTRICTED DATA

~~ATOMIC ENERGY ACT OF 1954~~

-81-

DECLASSIFIED IN FULL  
 Authority: EO 13526  
 Chief, Records & Declass Div, WHS  
 Date: MAY 29 2015

SECRET RESTRICTED DATA

  
 VAN NUYS, CALIFORNIA

REPORT 76

ATOMIC ENERGY ACT OF 1954

TABLE 7 (Continued)

Parameter	(1) Basic Model MA50-XCA System (Ref. 3)	(2) Length- Optimized Model MA50-XCA System (Ref. 4)	(3) Temperature Dependent Thermal Stress Properties for 15,000 psi	(4) Temperature Dependent Thermal Stress Properties for 18,000 psi	(5) Increase of Base Block Billet Size	(6) Reduced Air Flow Per Tie Rod	(7) Increase of Reactor Void Fraction
Thrust Coefficient Dif- ferential from Basic MA50-XCA, $\Delta C_{FAr}$	--	0.006	0.005	0.010	0.005	0.001	0.002
Percent Increase in Thrust Coefficient from Basic MA50-XCA, %	--	+3	+2.5	+5	+2.5	+0.5	+1.

Constants: Inlet total pressure,  $P_{t0}$  393 psig Maximum core wall temp.,  $T_w$  2950°RInlet total temperature,  $T_{t0}$  1400°R Reactor diameter,  $D_R$  57 in. max.Inlet pressure recovery, Reactor area,  $A_R$  17.70 ft<sup>2</sup>

$$P_{t1}/P_{t0} \quad 0.807$$

SECRET RESTRICTED DATA

ATOMIC ENERGY ACT OF 1954

-82-

DECLASSIFIED IN FULL

Authority: EO 13526

Chief, Records &amp; Declass Div, WHS

Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

(1) The basic Model MA50-XCA propulsion system performance is presented to provide a basis for comparison of the following items. A detailed discussion of the basic Model MA50-XCA propulsion system was presented in Performance Bulletin No. 2 (Reference 3).

(2) The length-optimized Model MA50-XCA propulsion system is characterized by the removal of four inches of forward reflector and 4 inches of the aft core. This version of the Model MA50-XCA was discussed in Performance Bulletin No. 3 (Reference 4).

(3) The basic Tory IIC reactor power profile presented in the Tory IIC Data Book (Reference 1) is determined by a maximum allowable elastic thermal stress of 15,000 psi and a maximum wall temperature of 2500°F. The stress calculation assumes that thermal conductivity, modulus of elasticity, and coefficient of expansion for beryllia are invariant with temperature and are evaluated at the 2500°F wall temperature. However, when the temperature dependence of these same properties is accounted for, an improved power profile is obtained which yields a constant 15,000 psi elastic thermal stress over the front portion of the core and a maximum allowable wall temperature of 2500°F over the rear portion. The resultant performance increase (thrust) is shown as 2.5 percent over the basic Model MA50-XCA. This increase is somewhat conservative; that airflow re-optimization would yield a slightly higher thrust.

(4) As an extension of the effort to improve the basic Tory IIC power distribution, a second computation was made using an elastic thermal stress limit of 18,000 psi in combination with a maximum wall temperature of 2500°F. For the same airflow rate as the basic Model MA50-XCA, a 5 percent gain in thrust was achieved. Power profiles for items (3) and (4) are compared to the basic Tory IIC profile in Figure 40.

(5) The basic design of the Tory IIC reactor is dependent upon the base-plate billet diameter. State-of-the-art in Niobium fabrication has indicated that this size might be increased from the present diameter of 5 inches to about 9 inches. This would allow a reduction in the total number of tie rods since the temperature of the tie rods is currently around 1250°F, providing a high margin of safety for allowable stress.

Reducing the number of tie rods in the core also reduces the volume occupied by unfueled cooling passages. By going to a 9-inch diameter billet, sufficient fueled region is added to the core to obtain a 2.5 percent increase in thrust over the basic Model MA50-XCA for the same airflow rate.

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

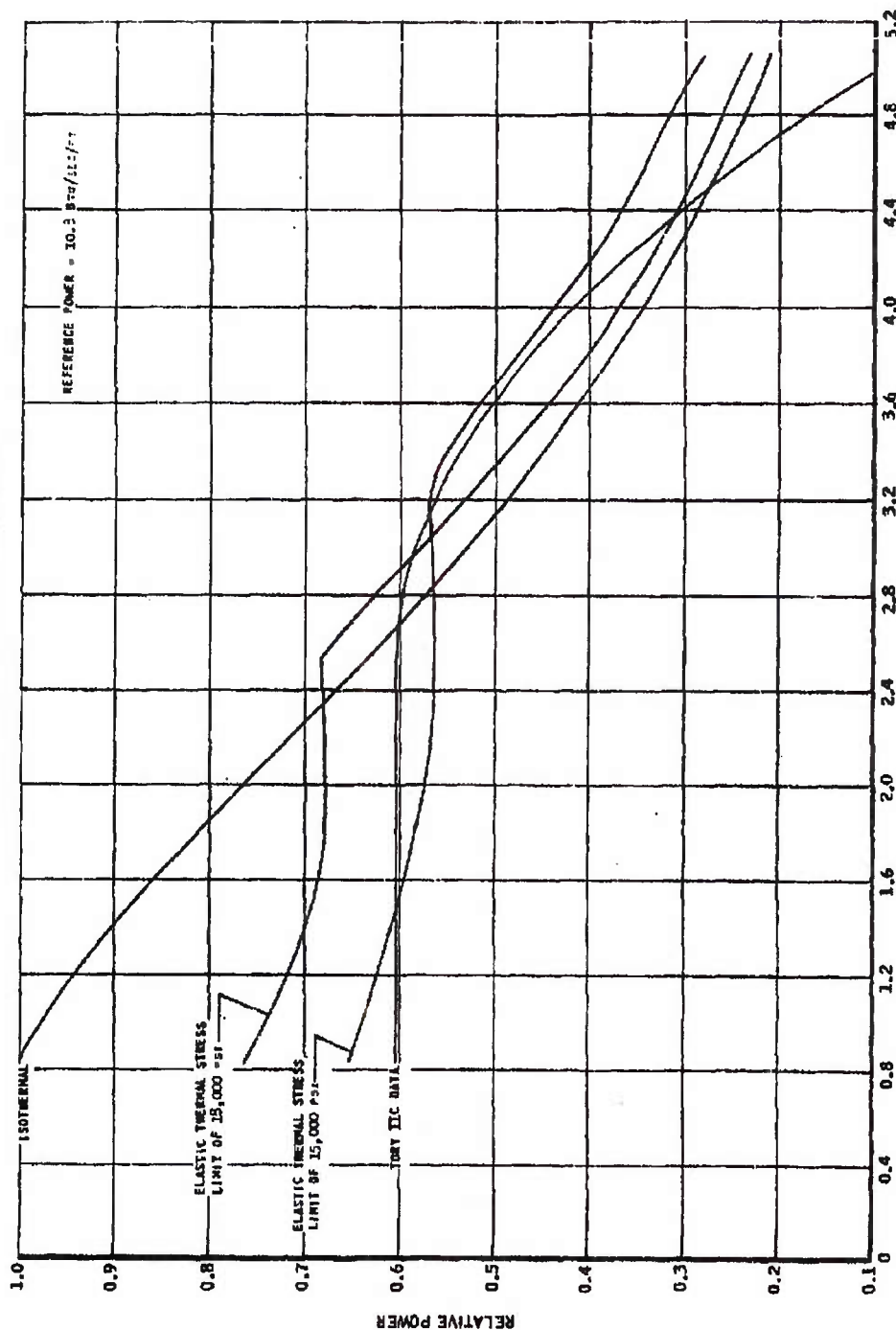


~~SECRET RESTRICTED DATA~~  
ATOMIC ENERGY ACT OF 1954

*The Marquardt Corporation*  
VAN NUYS, CALIFORNIA

REPORT 58

COMPARISON OF RELATIVE CORE POWER PROFILES



~~SECRET RESTRICTED DATA~~

N22E619A ATOMIC ENERGY ACT OF 1954 -84-

DECLASSIFIED IN FULL FIGURE 40  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

1 DRT 5876

~~ATOMIC ENERGY ACT OF 1954~~

(6) As a further step in the investigation of possible performance gains, a study was made of the effect of increasing the rod temperature. Since a considerable margin of safety exists at the temperature (1250°F) predicted for the Model MA50-XCA engine, an increase in the rod operating temperature appears quite feasible. Accordingly, the diameter of the tie rod cooling channel was reduced until a tie rod temperature of 1650°F was attained. The engine was then optimized for air flow. A relatively modest 0.5 percent increase in thrust was achieved over the basic Model MA50-XCA engine.

(7) The internal diameter of the current Tory HIC fuel element is 0.227 inches. To determine the effect on thrust of a small change in reaction, performance calculations were made using a tube internal diameter of 0.230 inches. This dimension was selected as representative of a minor change of geometry that would not greatly affect the fuel loading allowable limit, gain for the same total airflow rate as the basic Model MA50-XCA, a 1 percent increase in thrust is achievable.

Although these parametric studies are based on the diameter of the Tory HIC reactor, the performance gains noted are applicable to the large diameter Model MA50-XDA propulsion system.

### 3.3.10 Neutronics

Neutronic studies of the Model MA50-XCA and the Model MA50-XDA propulsion systems have been reported in previous performance bulletins (References 3 and 4, respectively). Neutronic analyses of the concepts presented in this fourth bulletin have not been made during this period, but will be discussed in succeeding reports.

### 3.3.11 Operating Envelopes

Preliminary propulsion system operating envelopes have been established for the Model MA50-XCA nuclear ramjet for the ANA Hot and Cold ICAO Standard Day temperatures, and are presented in Figures 41, 42, and 43, respectively. Limits for these envelopes have been established as follows:

The Mach 2.0 lower limit was established arbitrarily. However, some basis for this selection arises from a requirement for a pressure ratio of 8 to 1 across certain pneumatic components. The upper altitude limit is established as a line of constant diffuser exit pressure of 45 psia (which assures the aforementioned 8 to 1 pressure ratio) up to 50,000 feet, the maximum altitude of interest.

MAC 603

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

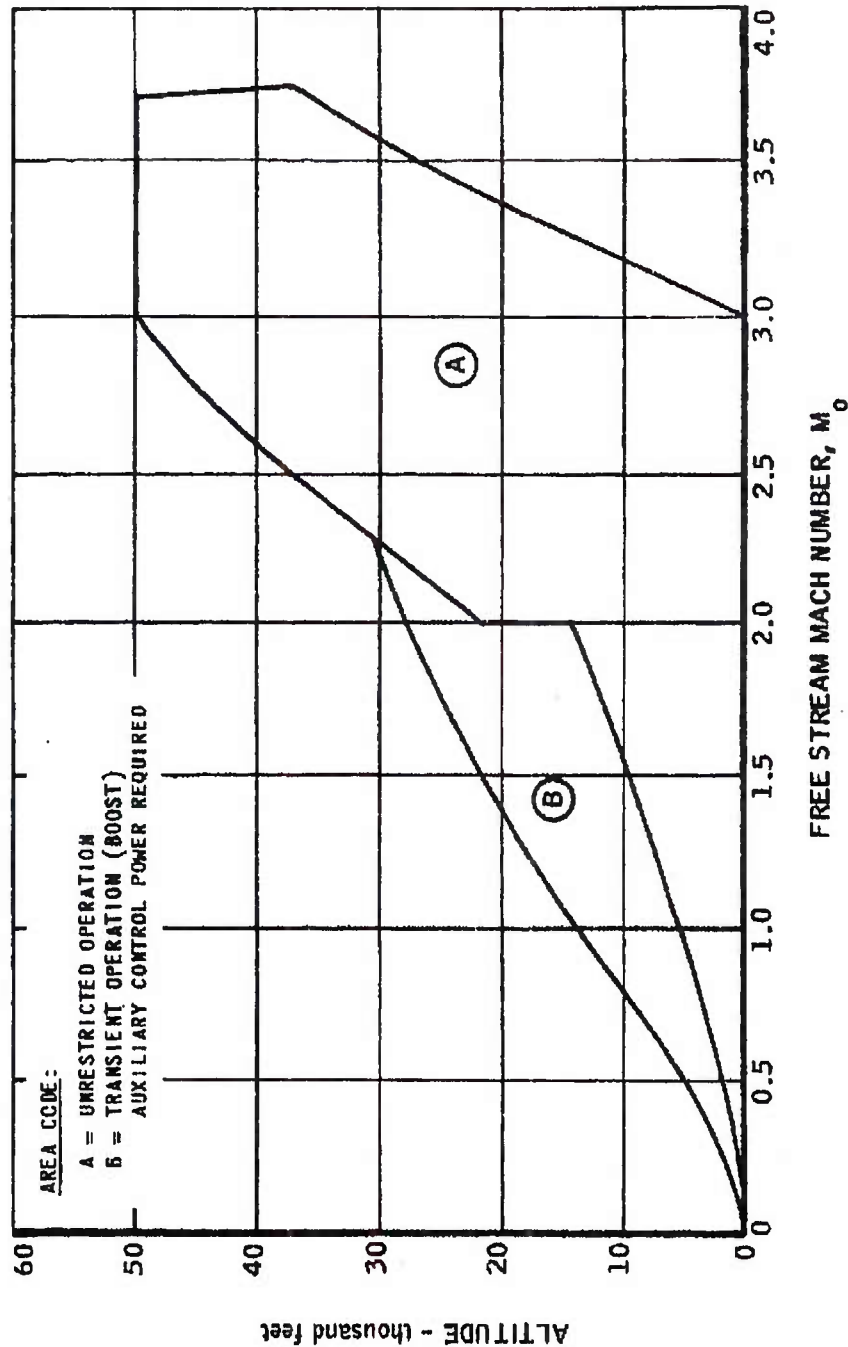
~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

*The Marquardt Corporation*  
VAN NUYS, CALIFORNIA

REPORT 5f 6

ESTIMATED ANA HOT DAY OPERATING ENVELOPE FOR THE MARQUARDT MODEL MA50-XCA RAMJET



~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

DECLASSIFIED IN FULL

Authority: EO 13526  
Chief, Records & Declass Div, WHIS  
Date: MAY 29 2015

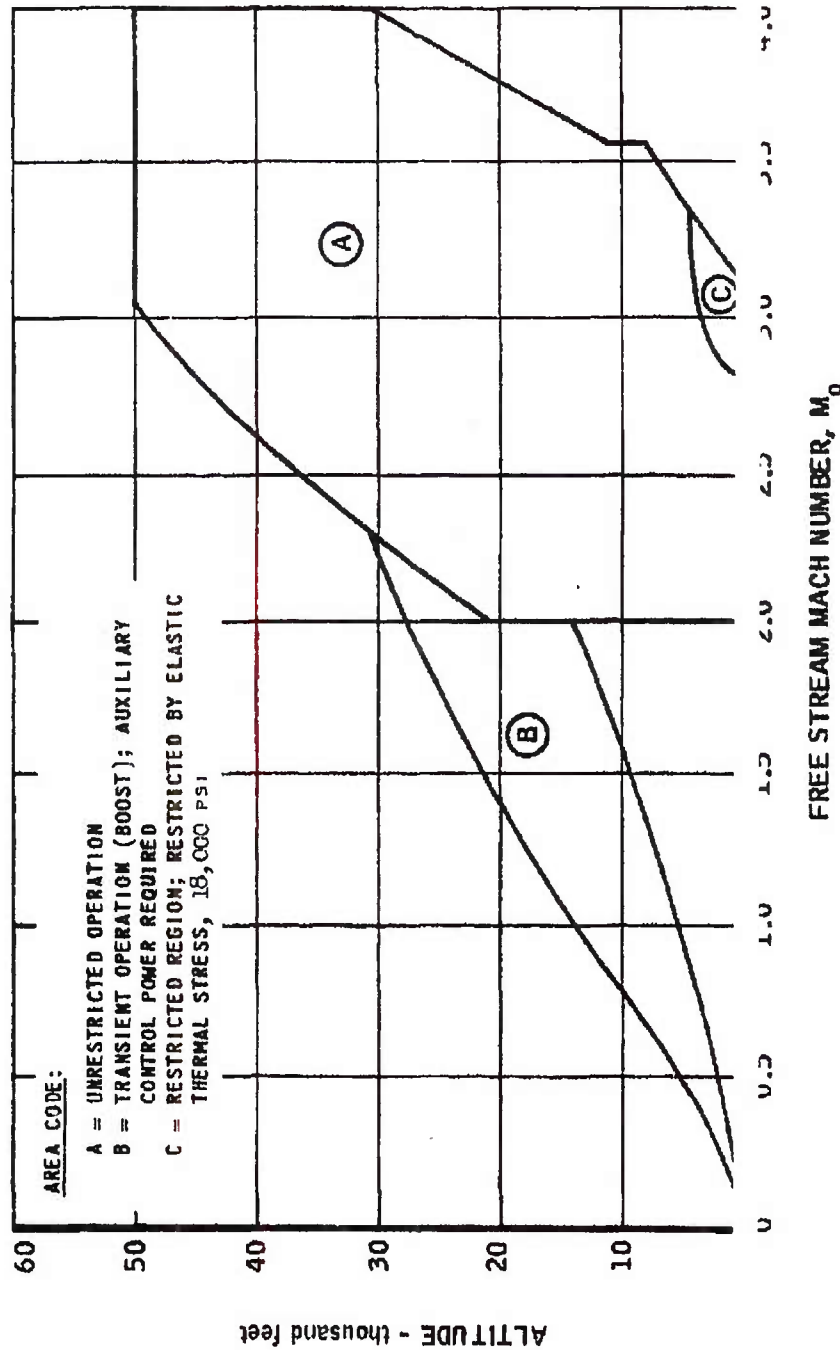
FIGURE 41

~~SECRET RESTRICTED DATA~~  
~~ATOMIC ENERGY ACT OF 1954~~

*The Marquardt Corporation*  
VAN NUYS, CALIFORNIA

5876

ESTIMATED ANA COLD DAY OPERATING ENVELOPE FOR THE MARQUARDT MODEL MA50-XCA RAMJET



MAC 423

~~SECRET RESTRICTED DATA~~

N22E621 ~~ATOMIC ENERGY ACT OF 1954~~

-87

DECLASSIFIED IN FULL

Authority: EO 13526

Chief, Records & Declass Div, WHS

Date: MAY 29 2015

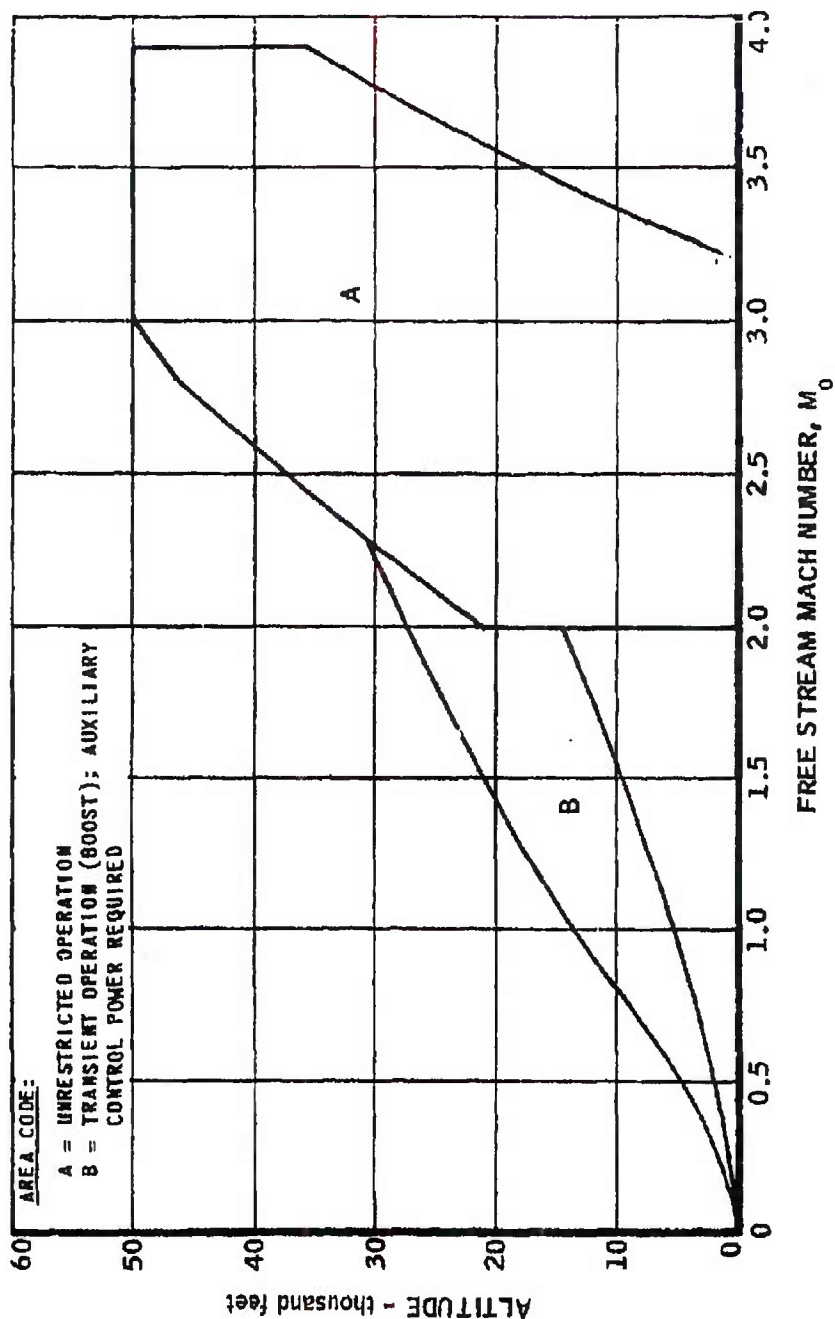
FIGURE 42



~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

ESTIMATED ICAO STANDARD DAY OPERATING ENVELOPE FOR  
 THE MARQUARDT MODEL MA50-XCA RAMJET



~~SECRET RESTRICTED DATA~~

~~N22E622 ATOMIC ENERGY ACT OF 1954~~

~~SECRET RESTRICTED DATA~~

PORT 5876

~~ATOMIC ENERGY ACT OF 1954~~

Limitation of the flight envelope at high speeds and altitude corresponds either to a ram air total temperature of 1070°F or a diffuser duct total pressure of 420 psia. At sea level, these conditions limit the maximum flight speed to Mach 3.0 at the ANA Hot Day temperature, to Mach 3.1 at ANA Cold Day temperature, and to 3.2 at ICAO Standard Day temperature.

Note is made of the restricted operating region in the flight envelope for the ANA Cold Day condition. The Tory IIC reactor power profile is defined by an elastic thermal stress limit of 15,000 psi and a maximum wall temperature of 2500°F at the design point. It is possible, under Cold Day conditions at high speed and low altitude, to attain a flow rate - core temperature condition wherein the 15,000-psi allowable stress limit will be exceeded. Based on successful operation of the Tory IIA reactor at powers above the design value, and in concurrence with LRL, the limiting elastic thermal stress for off-design operation has been increased to 18,000 psi. Raising the stress limit has the effect of reducing the restricted operating region to the small area shown in Figure 4. To operate in the restricted region, air flow and core temperature must be adjusted in such a manner that the 18,000-psi stress limit will not be exceeded.

The missile must be boosted into the propulsion system operating envelope. Typical boost envelopes are shown in Figures 41, 42, and 43.

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

~~SECRET RESTRICTED DATA~~

ATOMIC ENERGY ACT OF 1954

### 3.4 HEAT TRANSFER AND THERMAL STRESS ANALYSIS

#### 3.4.1 Mechanical and Structural Design Support Studies

##### Inlet

The heat transfer effort directed toward the design of the propulsion system inlet assembly has been of a preliminary nature. Estimates of some steady state temperatures have been made for the following conditions: Mach 2, ANA Hot Day, an altitude of 1,000 feet, and Mach 3.0, ANA Hot Day, an altitude of 1,000 feet. The underslung axisymmetric variable-geometry inlet analyzed shown in Figure 44.

At the Mach 3.0 condition, calculations indicated that a temperature of about 1300° F may be expected with the airflow distribution shown in Figure 44. It was assumed that the inlet bleed airflow that enters the boundary layer bleed slot was used for cooling purposes. Half of this flow is directed forward in the centerbody while the other half is directed aft. At the time of the study, the forward-directed flow was channeled aft before it had a chance to cool the forward-most section of the translating mechanism; consequently, this section reached temperature of approximately 1300° F. At the Mach 2.8 condition, the temperature of this section is 1130° F. The steady state temperatures calculated for portions of the inlet at the Mach 3.0 and Mach 2.8 conditions are presented in Figure 44. Later design configurations provide for passing a portion of the cooling air through this forward section, thereby lowering the temperatures shown in Figure 44.

The inlet actuating mechanism presents the greatest potential heat transfer problem in the entire inlet assembly. This mechanism, which has recently been defined, will be analyzed to determine cooling requirements. The cowl assembly, which has not been fully analyzed, is not expected to reach temperatures higher than those of Figure 44.

##### Side Support Structure

The results and a discussion of the heat transfer studies of the Models MA50-XCA and MA50-XDA side support systems are presented in Section 3.4.

##### Reactor Tie Tubes

The steady state temperatures in a Tory II C reactor tie tube (R-235 material) have been determined for design point conditions. The tie tube

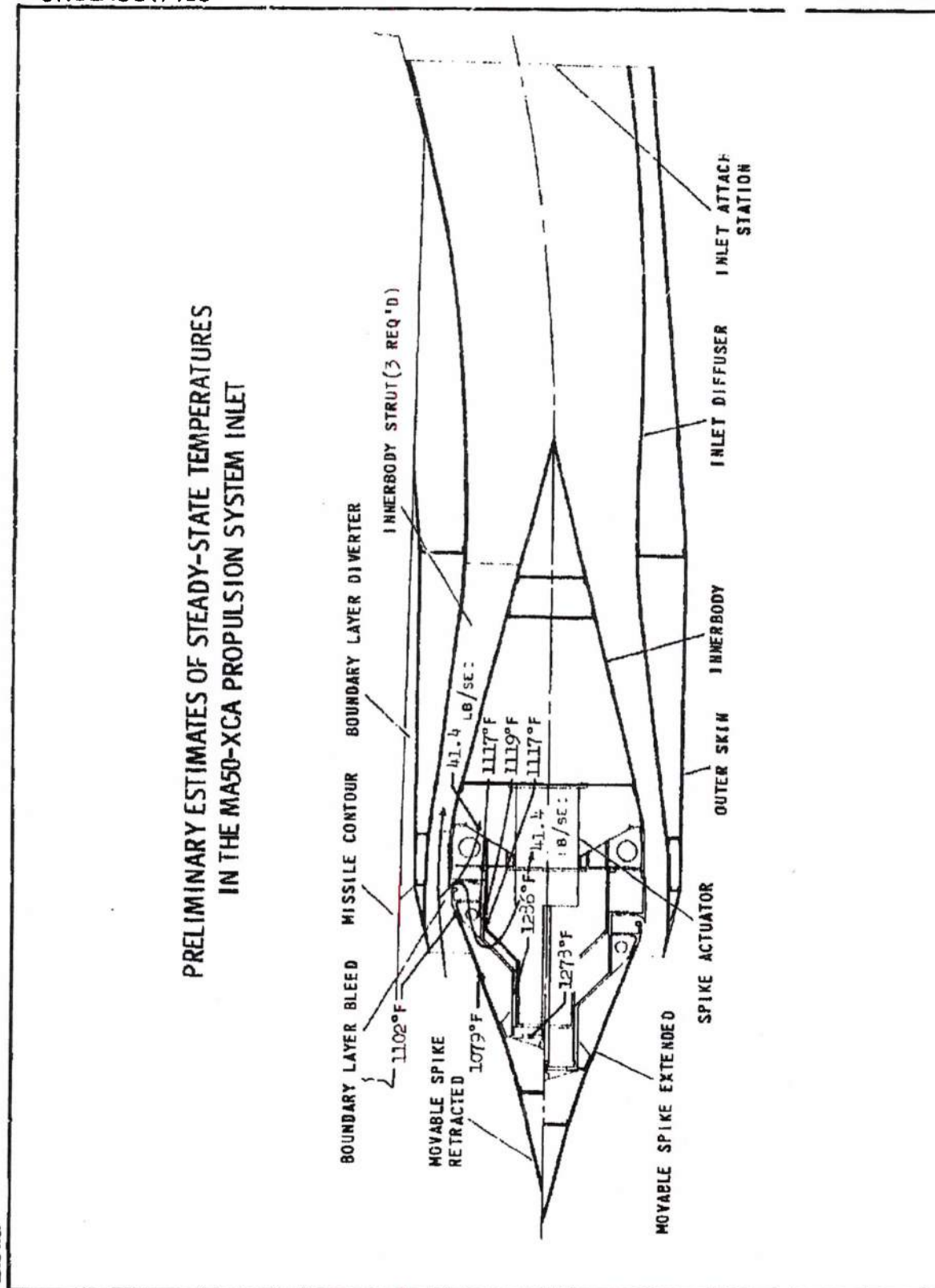
~~SECRET RESTRICTED DATA~~

ATOMIC ENERGY ACT OF 1954

UNCLASSIFIED

# PRELIMINARY ESTIMATES OF STEADY-STATE TEMPERATURES IN THE MA50-XCA PROPULSION SYSTEM INLET

MAC 467



22E641 UNCLASSIFIED



~~SECRET RESTRICTED DATA~~

REPORT 58

~~ATOMIC ENERGY ACT OF 1954~~

considered was located near the reactor centerline. The temperatures of the unfueled beryllia surrounding the tie tube and the temperature rise of all cooling air streams were determined. The following values were obtained:

	Temperature (°F)
Maximum temperature of unfueled beryllia	2570
Air temperature rise in unfueled beryllia	1250
Maximum temperature of tie tube	1250
Air temperature rise in tie tube	110

Complete temperature distributions in the tie tube and surrounding unfueled beryllia are presented in Figure 45. Some specific conditions used in the study are presented in Table 8.

More recent studies of a similar nature were conducted at the following conditions: Mach 3.0, ANA 421 Hot Day, sea level; and Mach 3.6, ANA 421 Hot Day, an altitude of 30,000 feet. The studies produced maximum tie tube temperatures of 1360° F and 1385° F, respectively. Additional off-design operation studies will be conducted in the future.

The tie tube configuration and the analytical models used are shown in Figure 46. The reactor length model was simulated by an IBM 704 thermal analyzer program, which may be used for a variety of conditions and tie tube materials.

#### Exhaust Nozzle

At the beginning of the contract year, several exhaust nozzle types were being considered for Pluto application. These nozzle types included the tubular forced convection, annular forced convection, baffle forced convection, film-cooled (or ejector), and radiation cooled configurations.

The baffled and the radiation cooled designs were eventually dropped for the reasons discussed in Section 3.2.2.

During the contract period, a considerable amount of detailed heat transfer analysis effort was devoted to the tubular, forced convection configuration. A preliminary analysis of the film-cooled (or ejector type) nozzle was also made.

The exit nozzle contour for the flight engine was established as a convergent-divergent, bell-shaped, fixed area type.

~~SECRET RESTRICTED DATA~~

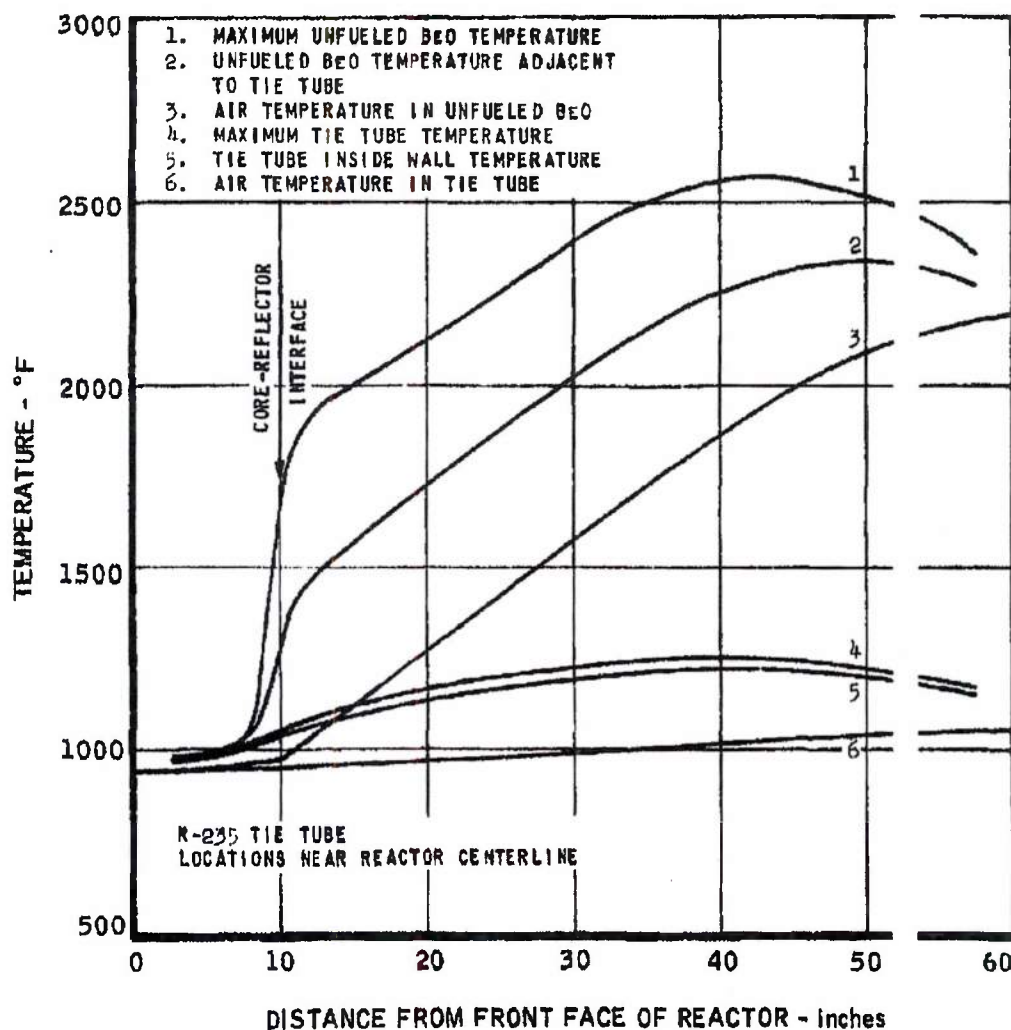
~~ATOMIC ENERGY ACT OF 1954~~

~~SECRET~~

*Marquardt*  
Insurance  
VAN NUYS, CALIFORNIA

PORT 5876

# STEADY-STATE TEMPERATURES IN A TORY IIC TIE TUBE AND SURROUNDING BERYLLIA AT DESIGN POINT CONDITION



DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WIS  
Date: MAY 29 2015

MAC AG3

N22J18 ~~SECRET~~

~~SECRET RESTRICTED DATA~~

REPORT 5876

ATOMIC ENERGY ACT OF 1954

TABLE 8  
CONDITIONS USED IN  
TORY HC TIE-TUBE HEAT TRANSFER STUDY

Item	Value
Tie Tube Material	R-235
Tie Tube Internal Diameter, in.	0.58
Tie Tube Outside Diameter, in.	0.66
Tie Tube Flow Area, sq. in.	0.264
Reactor Length, in.	60
Nuclear Heating in Tie Tube	Axial Profile
Nuclear Heating in Unfueled Beryllia	Axial Profile
Air Weight Flow Rate in Tie Tube, lb/sec	0.73
Air Weight Flow Rate in Unfueled Beryllia Tube, lb/sec	0.017
Unfueled Beryllia Void Fraction	0.148
Diameter of Hole in Unfueled Beryllia Tube, in.	0.12
Unfueled Beryllia Tube Flow Area, sq. in.	0.0113
Unfueled Beryllia Tube Solid Area, sq. in.	0.0649
Temperature of Fueled Beryllia, °F	Axial Profile
Thermal Conductivity of Unfueled Beryllia Btu/hr/ft/°F	9.0
Thermal Conductivity of Tie Tube, Btu/hr/ft/°F	13.0
Heat Transfer Coefficient in Tie Tube, Btu/hr/ft <sup>2</sup> /°F	713.0
Heat Transfer Coefficient in Unfueled Beryllia Tube, Btu/hr/ft <sup>2</sup> /°F	615.0

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

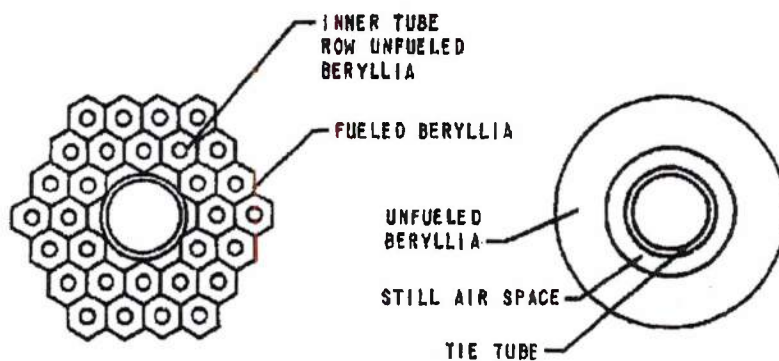
ATOMIC ENERGY ACT OF 1954

CONFIDENTIAL

THE Marquardt  
CORPORATION  
VAN NUYS, CALIFORNIA

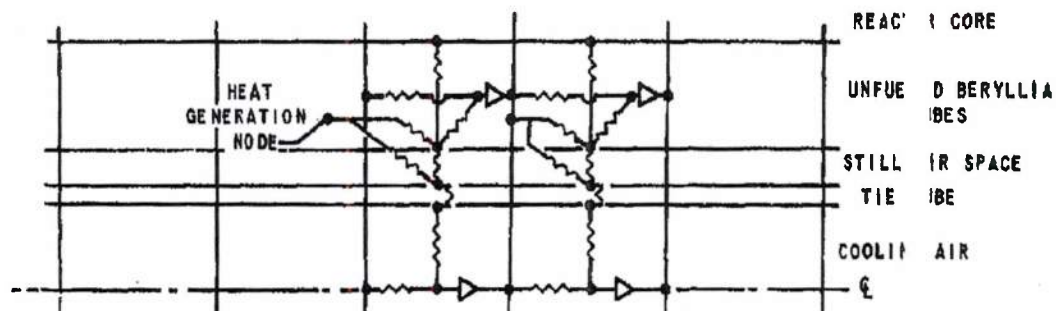
DRT 5876

## TORY IIC TIE TUBE CONFIGURATION AND ANALYTICAL MODELS



(A) TORY IIC TIE TUBE CONFIGURATION

(B) ANALYTICAL MODEL OF TIE TUBE CONFIGURATION



(C) NETWORK REPRESENTATION OF REACTOR TIE TUBE MODEL FOR THERMAL ANALYZER

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

MAC 467

22B8 ~~CONFIDENTIAL~~





~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

### Tubular, Forced Convection Nozzle

Two tube shapes were considered for the typical wire-wrapped nozzle of Figure 47. The first type analyzed had 402 tubes of rectangular cross section, as shown in Figure 48. Each tube was assumed to have a constant flow area of 0.1105 square inches along the length of the nozzle. The assumed cooling air available to the nozzle at this time was 50 lb/sec at 1200° F. It was assumed that heat is exchanged between the outer surface of the cooling tubes and the aerodynamic nozzle shroud by thermal radiation only. Maximum steady state tube temperatures were calculated to be 1488° F at Mach 3.0, sea level, ANA Hot Day, and 1456° F at Mach 3.0, sea level, ANA Cold Day.

Structural analysis indicated that round tubes would offer much greater strength; consequently, the analysis of the square tube was dropped.

In the round tube configuration the tubes (0.375-inch ID x 0.01 inch wall) were held at a constant perimeter rather than a constant flow area. The first analysis of a round tube yielded a maximum tube temperature of 1555° F at Mach 3.0, sea level, and ANA Hot Day conditions. This study was repeated once omitting internal heat generation and again omitting both internal heat generation and reactor thermal radiation. The maximum tube temperatures obtained from these studies were 1555° F and 1548° F, respectively.

Next, a preliminary optimization study was made to determine maximum tube temperatures as a function of tube size. The results of this study are presented in Figure 49 where maximum nozzle-tube temperature and total nozzle-tube weight are plotted against the inside diameter of the tube. In this study, the tube wall thickness (0.010 inches) and cooling airflow (50 lb/sec) were held constant. The temperatures along the length of the nozzle are shown in Figure 50.

All of the nozzle heat transfer studies discussed above were based on a coolant airflow rate of 50 lb/sec at 1200° F. Later information from LRL specified the coolant airflow rate to be 113 lb/sec and at a lower temperature. The temperature of this cooling air, which passes through the side support structure spring compartment, is about 1000° F. A tube size of approximately 13/16-inch outside diameter with a wall thickness of 0.020 inches is necessary for this flow. The nozzle design utilized 240 of these tubes. A study was made to evaluate the heat transfer characteristics of this system at two design operating conditions: Mach 2.8, ANA Hot Day, an altitude of 100 feet; and Mach 2.8, ANA Cold Day, an altitude of 1000 feet. Pertinent

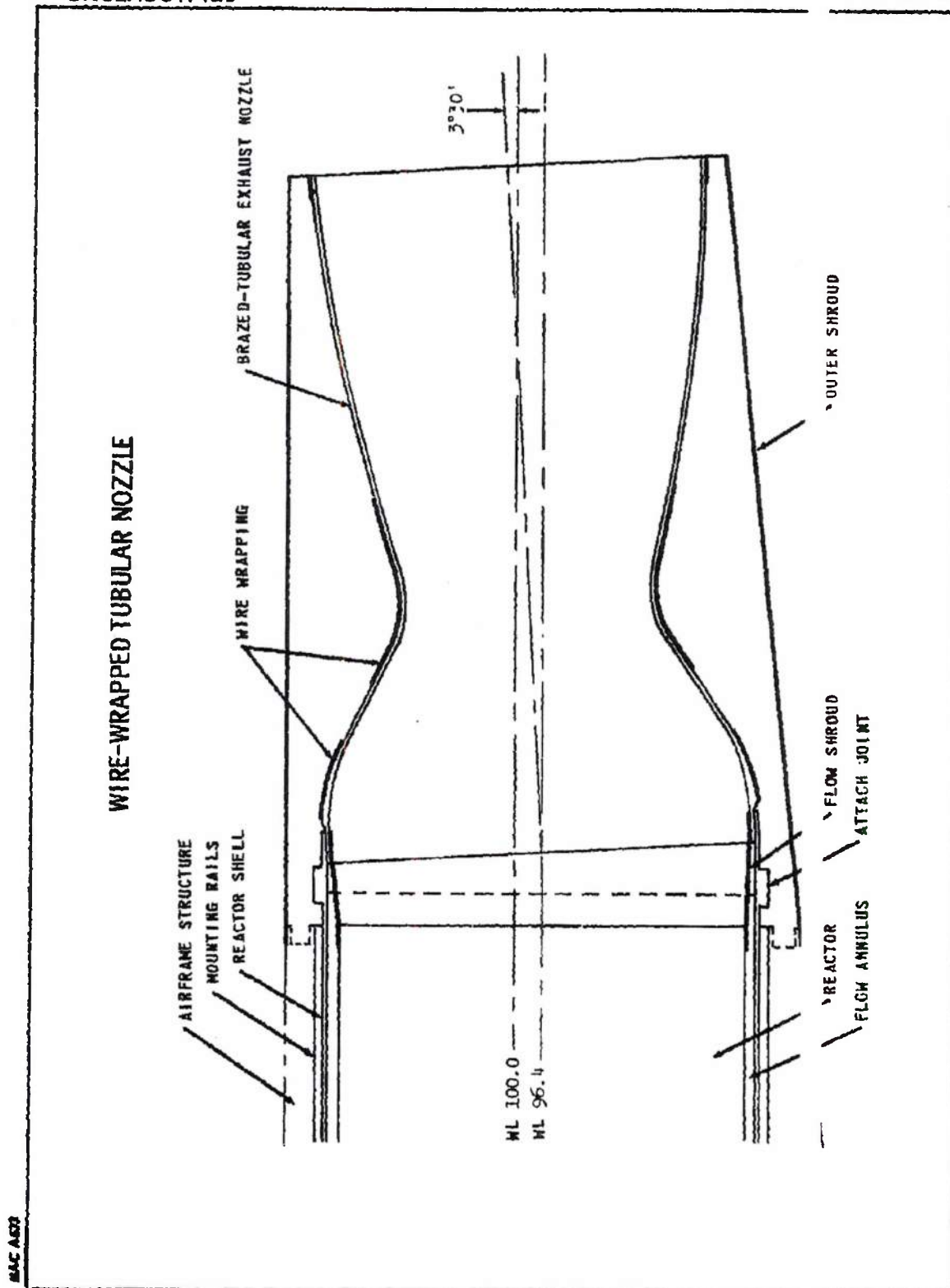
~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

UNCLASSIFIED

*The Marquardt Company*  
 VAN NUYS, CALIFORNIA

RI RT 5876



22B16 UNCLASSIFIED

-97-

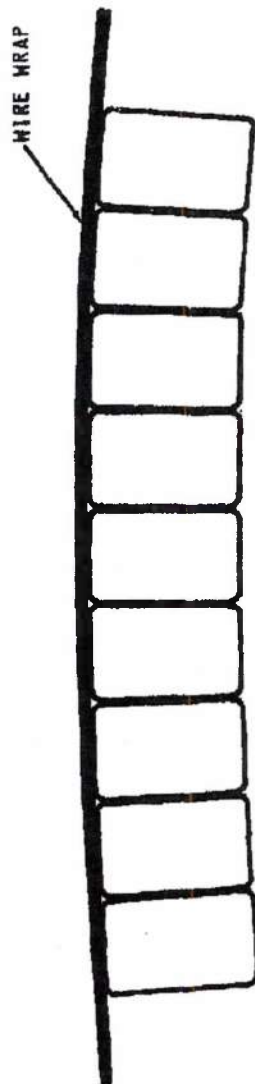
FIGURE 47

UNCLASSIFIED

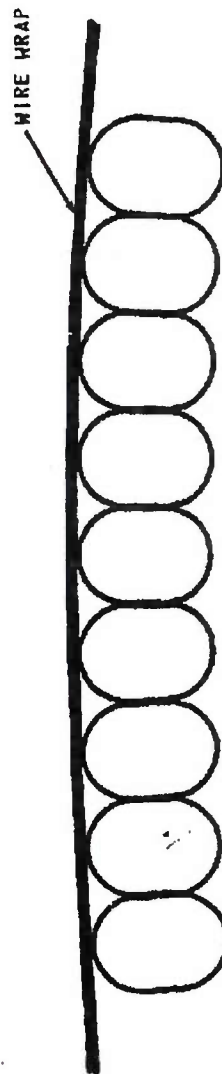
*The Marquardt Corporation*  
VAN NUYS, CALIFORNIA

REPORT 51 6

TUBULAR WIRE-WRAPPED CONFIGURATIONS FOR PLUTO ENGINE EXHAUST NOZZLE



A. RECTANGULAR TUBES OF CONSTANT FLOW CROSS-SECTION



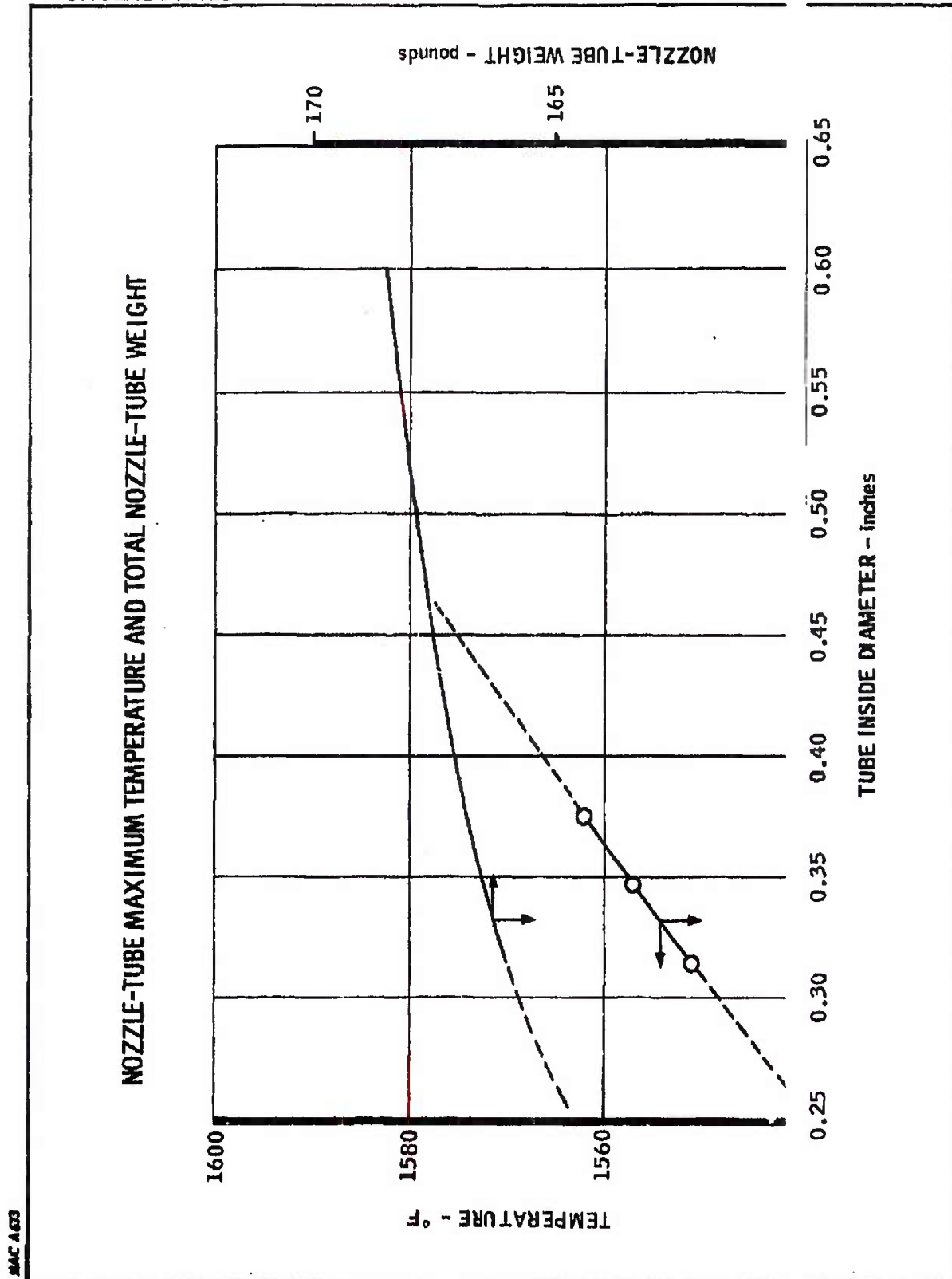
B. ROUND TUBES OF VARIABLE FLOW CROSS-SECTION

Page determined to be Unclassified  
Reviewed Chief, RDD, WHS  
IAW EO 13526, Section 3.5  
Date: MAY 29 2015

UNCLASSIFIED

*The Marquardt Corporation*  
 VAN NUYS, CALIFORNIA

PORT 5876



MAC A 673

15B4 UNCLASSIFIED

-99-

FIGURE 49



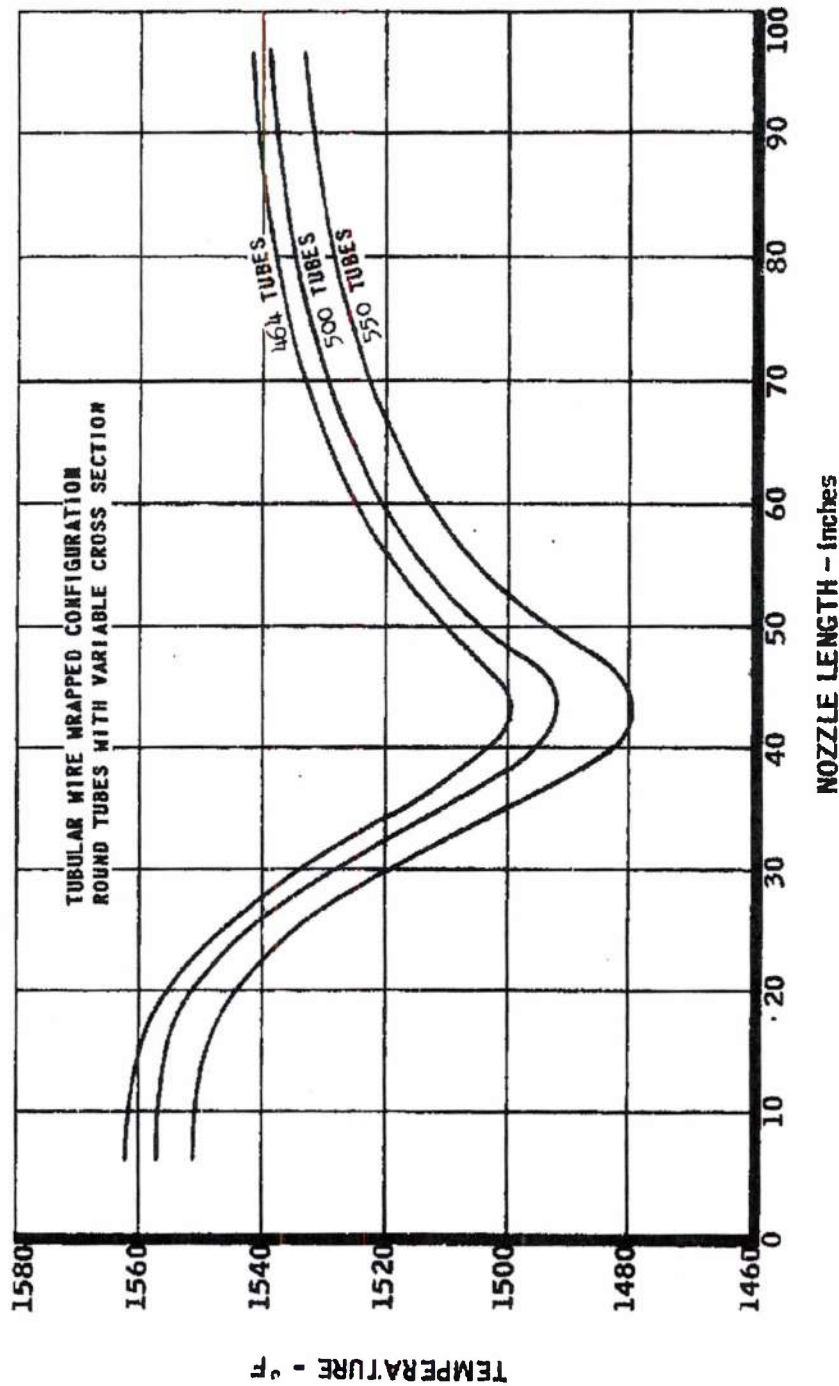
MAY 29 2015

*The Marquardt*  
VAN NUYS, CALIFORNIA

REPORT 58

UNCLASSIFIED

STEADY-STATE TEMPERATURES IN A PLUTO ENGINE EXHAUST NOZZLE



MAC A37

15B5 UNCLASSIFIED

-100-

FIGURE 50

MAY 29 2015



~~SECRET RESTRICTED DATA~~

VAN NUYS, CALIFORNIA

REFC

5876

ATOMIC ENERGY ACT OF 1954

Information for these two conditions is presented in Table 9. The results of the study are presented in Figures 51 and 52. The maximum tube temperature at the design point condition is about 1500° F and occurs at the exit end. For the off-design condition (Cold Day), the maximum temperature, about 1230° F, also occurs at the exit end.

The present nozzle design reflects a slightly changed internal contour. In addition, the flow was reduced to 100 lb/sec at a temperature of 1050° F. The 240 R-235 alloy cooling tubes (0.75-inch ID x 0.028-inch wall) are found at the entrance end. In order to conform to the nozzle contour, these tubes are compressed or flattened, and the cross section takes on a wedge shape as shown in Figure 53. At design point conditions, the maximum tube temperature for this configuration is 1475° F and occurs at the nozzle exit. The temperature distribution in the nozzle is presented in Figure 54. Off-design operating studies are presently being conducted.

#### Annular, Forced Convection Nozzle

The nozzle cooled by an annular, concentric cooling chamber is similar to the tubular nozzle in terms of simulation on the IBM 704 thermal analyzer program. Only minor modifications of the existing computer program were necessary to produce a program for this nozzle. It is planned to evaluate steady state temperatures for this nozzle design.

#### Ejector or Film Cooled Nozzle

A study was made to obtain a preliminary estimate of the steady state metal temperatures in an ejector type, or film-cooled, exhaust nozzle for the Model MA50-XCA propulsion system at design point conditions. It was assumed that the convergent portion of the nozzle consisted of wire-wrapped tubes, as previously described for the tubular nozzle. The cooling tubes (0.75-inch ID x 0.028-inch wall) passed cooling air at 113 lb/sec with an inlet temperature of approximately 1000° F. The divergent portion of the nozzle was considered to be a simple single shell extending from the outer surface of the wire-wrapped tubes. This divergent portion of the nozzle was film-cooled by the air issuing from the cooling tubes slightly aft of the throat position. The temperature of the discharge air was calculated to be at 1100° F.

The film cooling achieved in the divergent portion of the nozzle is quite effective. A nozzle metal temperature of 1240° F was calculated at the exit end of the divergent portion, which represents a reduction of about 260° F from

MAC 607

~~SECRET RESTRICTED DATA~~

ATOMIC ENERGY ACT OF 1954

~~SECRET RESTRICTED DATA~~

REPORT 587

~~ATOMIC ENERGY ACT OF 1954~~

TABLE 9

CONDITIONS OF HEAT TRANSFER STUDY OF MA50-XCA EXHAUST NOZZ E

Item	Design Point	Off-Design Point
Mach Number	2.8	2.8
Altitude, ft	1000	1000
ANA Day	Hot	Cold
Reactor Power, Mw	516	626
Reactor Exhaust Air Total Temperature, °F	2060	2034
Reactor Exhaust Airflow, lb/sec	1577	1624
Coolant Air Inlet Temperature, °F	1008	670
Coolant Airflow Rate, lb/sec	113	129

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

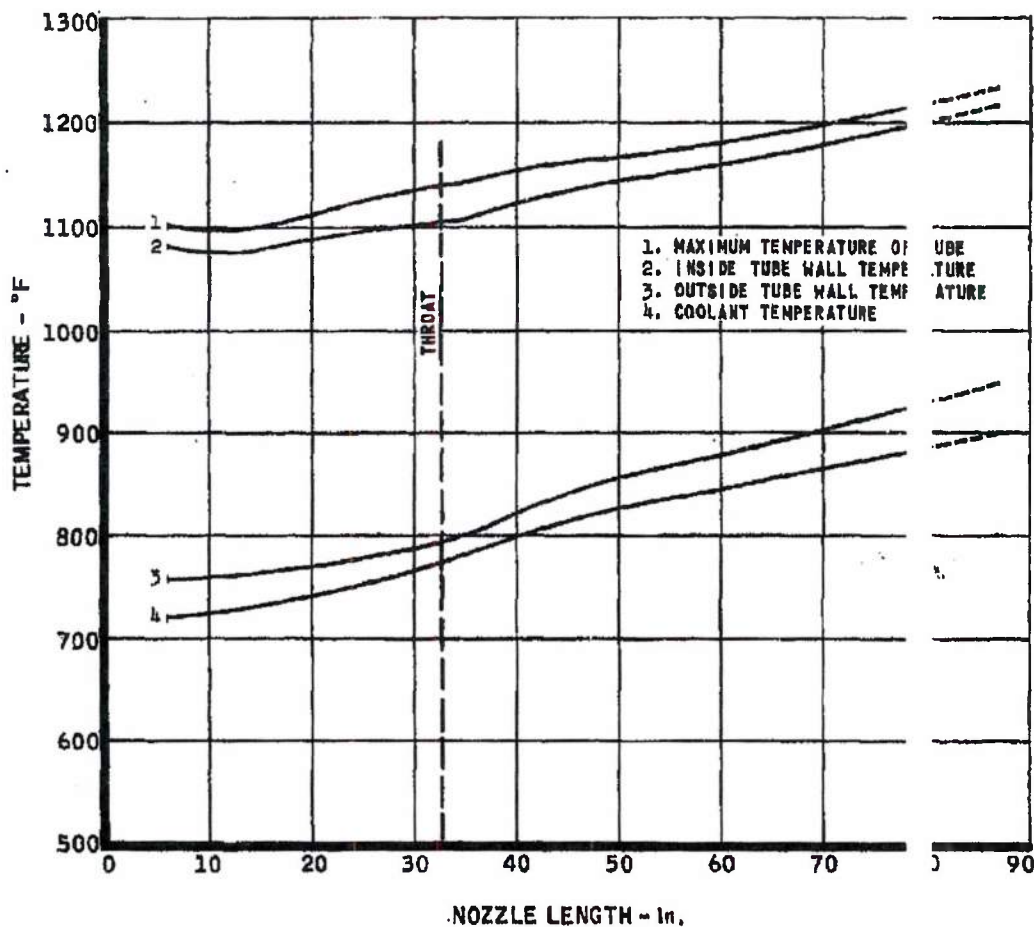
~~SECRET RESTRICTED DATA~~

*Marquardt*  
VAN NUYS, CALIFORNIA

5876

~~ATOMIC ENERGY ACT OF 1954~~

STEADY-STATE TEMPERATURES OF WIRE-WRAPPED TUBULAR EXHAUST NOZZLE  
AT MACH 2.8, 1,000 FEET, ANA COLD DAY, 626-MW REACTOR POWER LEVEL



DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

N22J19 ~~ATOMIC ENERGY ACT OF 1954~~ -103-

FIGURE 51

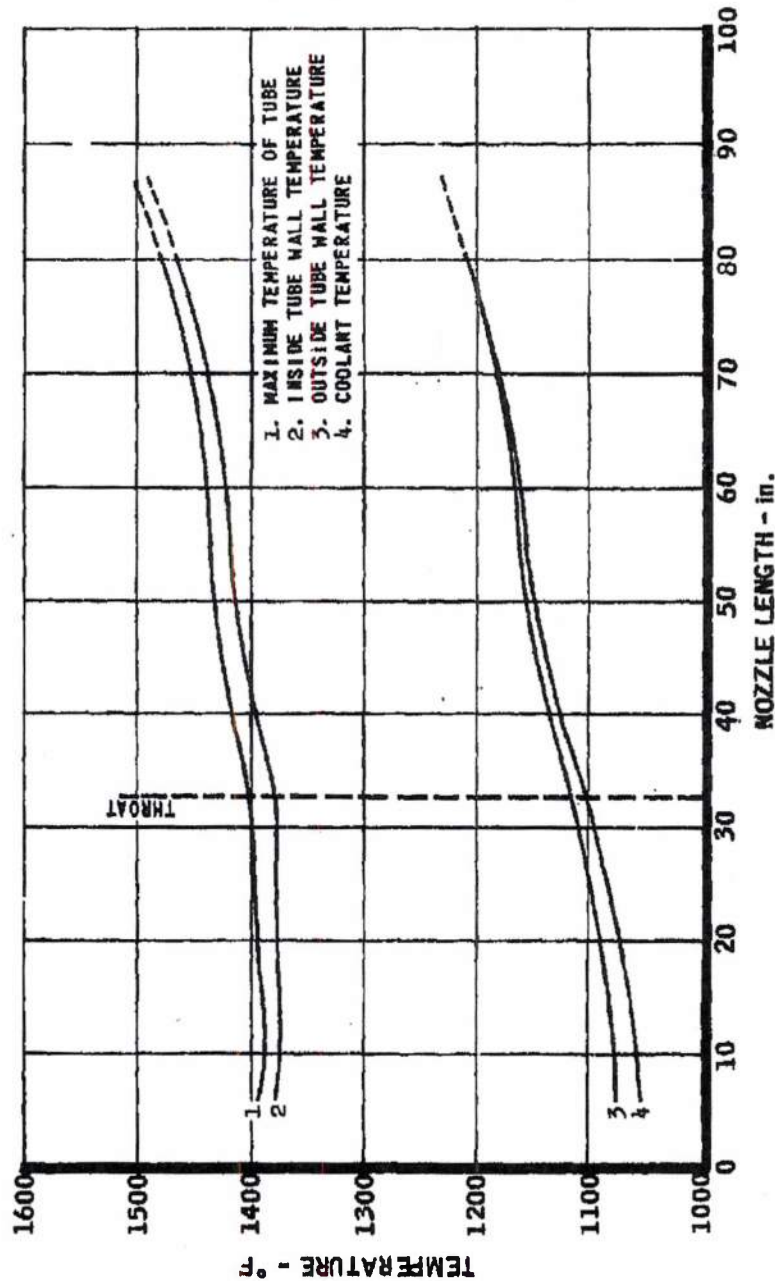


~~SECRET RESTRICTED DATA~~

REPORT 58

~~ATOMIC ENERGY ACT OF 1954~~

STEADY-STATE TEMPERATURES OF WIRE-WRAPPED TUBULAR EXHAUST  
 NOZZLE AT MACH 2.8, 1,000 FEET, ANA HOT DAY, 516-MW REACTOR POWER LEVEL



~~SECRET RESTRICTED DATA~~

N22J20

~~ATOMIC ENERGY ACT OF 1954~~

-104-

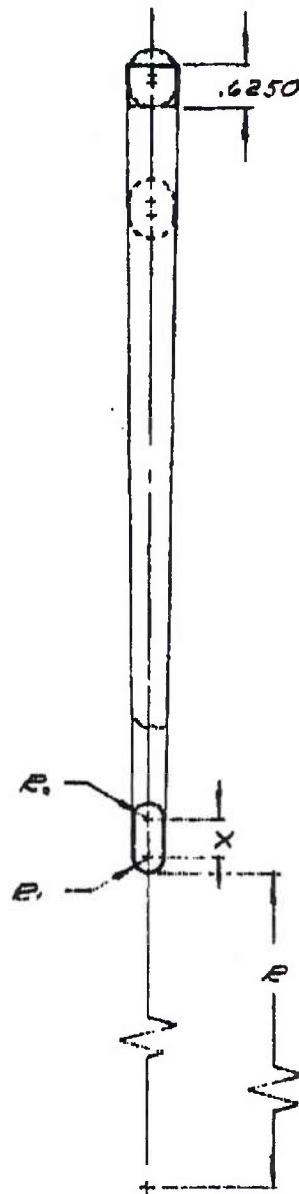
FIGURE 52

UNCLASSIFIED

*Marquardt*  
VAN NUYS, CALIFORNIA

ST 5876

## PHYSICAL DIMENSIONS OF EXHAUST NOZZLE COOLING TUBE



STA.	R	R <sub>i</sub>	R <sub>o</sub>	X	INFER	12
(in.)	(in.)	(in.)	(in.)	(in.)	Eq. 1	
0.000	0.62"x1	1/2° Trapezoidal		Shape	.40	}
3.000	0.62"x1	1/2° Trapezoidal		Shape	.40	
6.000	27.64	.366	.368	.122	.41	}
7.871	27.385	.363	.363	.133	.44	
11.912	26.303	.349	.351	.177	.44	
15.703	24.534	.325	.329	.249	.43	
16.750	23.924	.317	.321	.274	.42	
18.750	22.769	.302	.306	.321	.41	
20.750	21.614	.287	.292	.369	.40	
22.750	20.460	.271	.277	.416	.39	
24.750	19.305	.256	.262	.463	.38	
26.750	18.150	.240	.247	.510	.36	
28.646	17.266	.229	.236	.546	.35	Throat
30.666	16.724	.221	.229	.568	.34	
32.750	16.542	.219	.227	.576	.34	
33.750	16.550	.219	.227	.573	.34	
33.868	16.570	.220	.228	.573	.34	
35.75	16.950	.225	.232	.559	.33	
37.75	17.455	.231	.238	.539	.33	
39.75	17.960	.238	.245	.518	.32	
41.75	18.465	.245	.251	.497	.31	
43.75	18.970	.251	.258	.477	.31	
45.75	19.475	.258	.264	.456	.30	Exit
47.75	19.980	.265	.271	.435	.30	
49.75	20.470	.271	.277	.415	.30	
51.75	20.940	.278	.283	.396	.40	
53.75	21.380	.283	.288	.378	.40	
55.75	21.800	.289	.294	.361	.40	
57.75	22.220	.294	.299	.344	.40	
59.75	22.590	.299	.304	.328	.40	
61.75	22.950	.304	.308	.314	.40	
63.75	23.270	.308	.313	.301	.40	
65.75	23.580	.312	.316	.288	.40	
67.75	23.880	.316	.320	.276	.40	
69.75	24.160	.320	.324	.264	.40	
71.75	24.420	.323	.327	.254	.40	
73.75	24.660	.327	.330	.244	.40	
75.75	24.880	.330	.333	.235	.40	
77.75	25.080	.333	.335	.227	.40	
79.75	25.280	.335	.338	.219	.40	
81.75	25.450	.338	.340	.212	.40	
83.75	25.620	.340	.342	.205	.40	
85.75	25.760	.342	.344	.199	.40	
87.85	25.865	.343	.345	.195	.40	

\*Transition Section Between Station 3.000 &amp; 6.000

Page determined to be Unclassified  
Reviewed Chief, RDD, WHS  
IAW EO 13526, Section 3.5  
Date: MAY 29 2015

BAC 603

UNCLASSIFIED

22B18

-105-

FIGURE 53

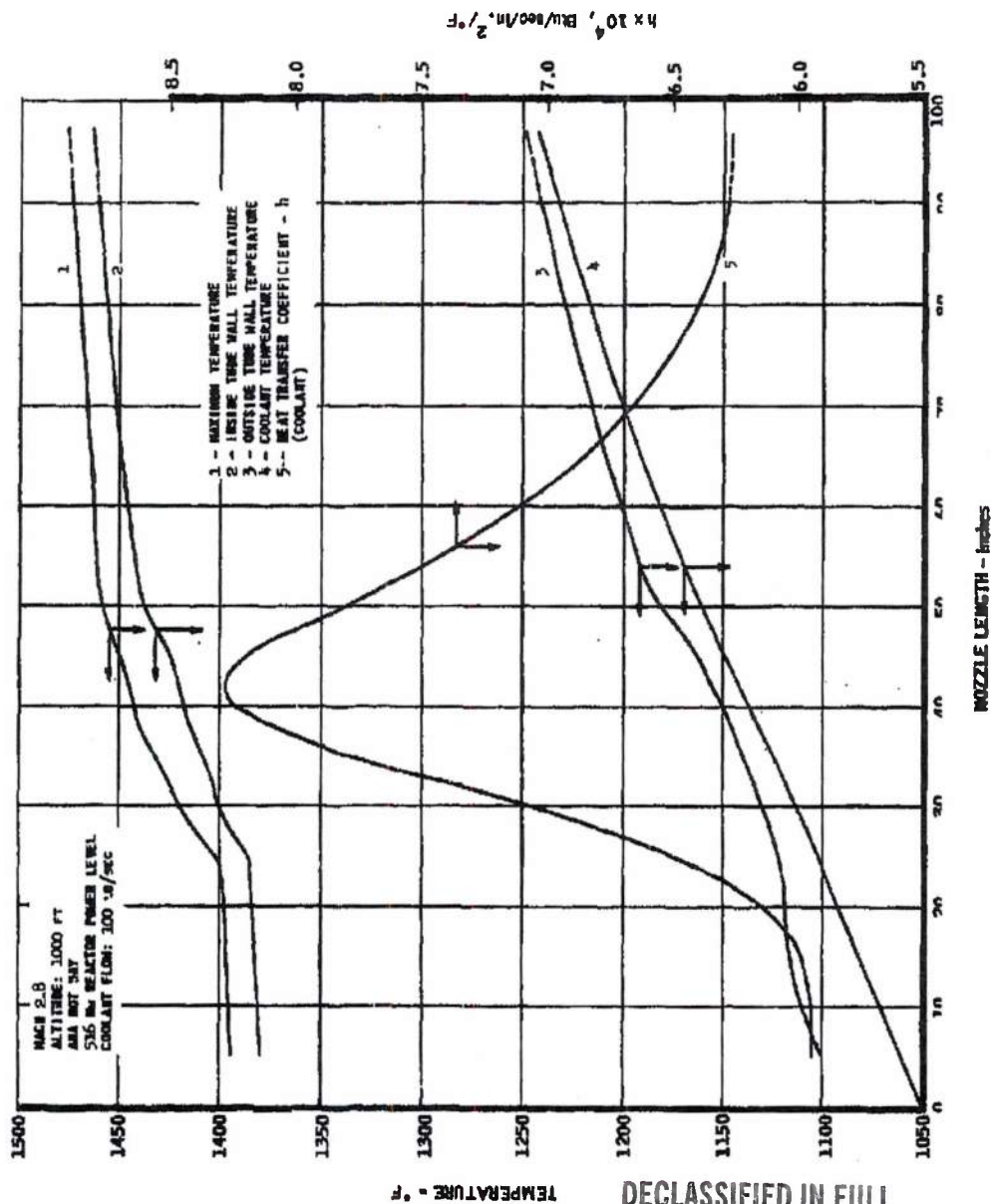
~~SECRET RESTRICTED DATA~~

*Marquardt*  
VAN NUYS, CALIFORNIA

REPORT 5 76

~~ATOMIC ENERGY ACT OF 1954~~

STEADY-STATE TEMPERATURES OF WIRE-WRAPPED TUBULAR EXHAUST NOZZLE  
OF MA50-XCA PROPUSSION SYSTEM



DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

N22J17 ~~ATOMIC ENERGY ACT OF 1954~~

-106-

FIG RE 54



~~SECRET RESTRICTED DATA~~

5876

~~ATOMIC ENERGY ACT OF 1954~~

that reported earlier for an all-tubular nozzle. However, the maximum metal temperature of the nozzle is about 1400° F and occurs in the convergent tubular portion at the throat position. A reduction in this value might be possible by using smaller tubes in the convergent portion; however, the pressure drop in the tubes and the balancing of the static pressures inside the nozzle and at the exit of the cooling tubes will be limiting factors. Figure 55 is a plot of the temperatures in the film-cooled nozzle.

An excellent correlation for the evaluation of film-cooling systems is presented in Reference 15. This method was used in the above analysis and has been successfully put in a form suitable for simulation by the IF 704 thermal analyzer program. A thermal analyzer program is now being constructed for future studies of ejector or film-cooled nozzles.

#### Nozzle Attachment Fitting

The flight engine nozzle attachment fitting shown in Figure 6 has been analyzed using the thermal analyzer to determine steady state temperatures at both Hot and Cold Day conditions (Mach 3.0, sea level). Maximum temperatures obtained for the Hot and Cold Day conditions are 1440° F and 1060° respectively. Temperature distributions are shown in Figure 57.

To determine the effect of heat generation in the fitting, an analysis was made under the same conditions with nuclear heating omitted. The maximum temperature for this case was 1202° F under Hot Day conditions indicating that nuclear heat generation accounted for 238° F of the nozzle attachment temperature.

At the present time, it is assumed that the nozzle attachment fitting of Figure 56 may be used on all air-cooled configurations of the exhaust nozzle.

### 3.4.2 Performance Support Studies

#### Heat Rejection Rates

Studies have been made to determine steady state temperatures and heat rejection rates in the Model MA50-XCA propulsion system side support structure. The primary objective of these studies was to estimate the heat rejection rates in the side support system for evaluation of propulsion system performance. For this reason, the analytical model chosen did not treat in detail each component as support springs. The analytical model used is shown in Figure 58.

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

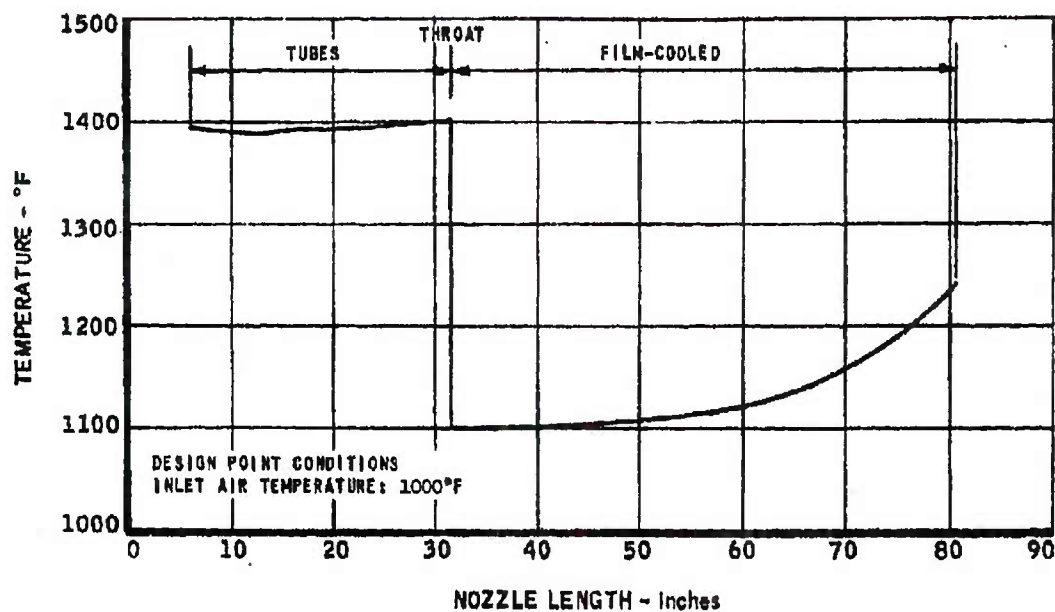


UNCLASSIFIED

*Marquardt*  
VAN NUYS, CALIFORNIA

REPORT 587

MAXIMUM STEADY-STATE METAL TEMPERATURES IN AN EJECTOR OR FILM-COOLED  
NOZZLE FOR THE MA50-XCA PROPULSION SYSTEM



Page determined to be Unclassified  
Reviewed Chief, RDD, WHS  
IAW EO 13526, Section 3.5  
Date: MAY 29 2015

ALC 403

22J22 UNCLASSIFIED

-108-

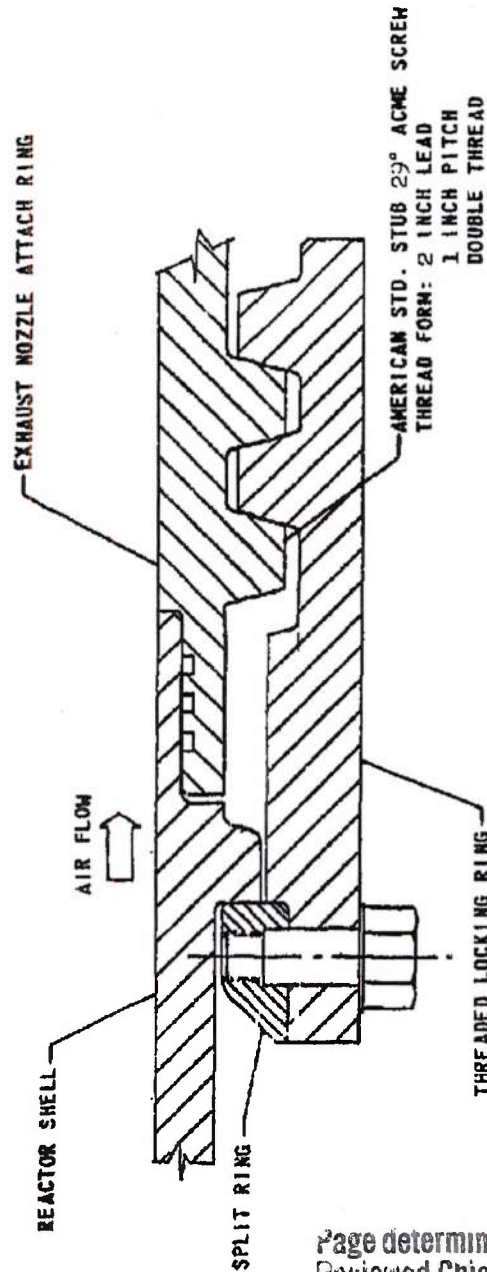
FIGUR 55

UNCLASSIFIED

*Marquardt*  
VAN NUYS, CALIFORNIA

1 DET 5876

# EXHAUST-NOZZLE-TO-REACTOR-SHELL ATTACHMENT



Page determined to be unclassified  
Reviewed Chief, RDD, WHS  
IAW EO 13526, Section 3.5  
Date: MAY 29 2015

MAC AGI

22B20 UNCLASSIFIED

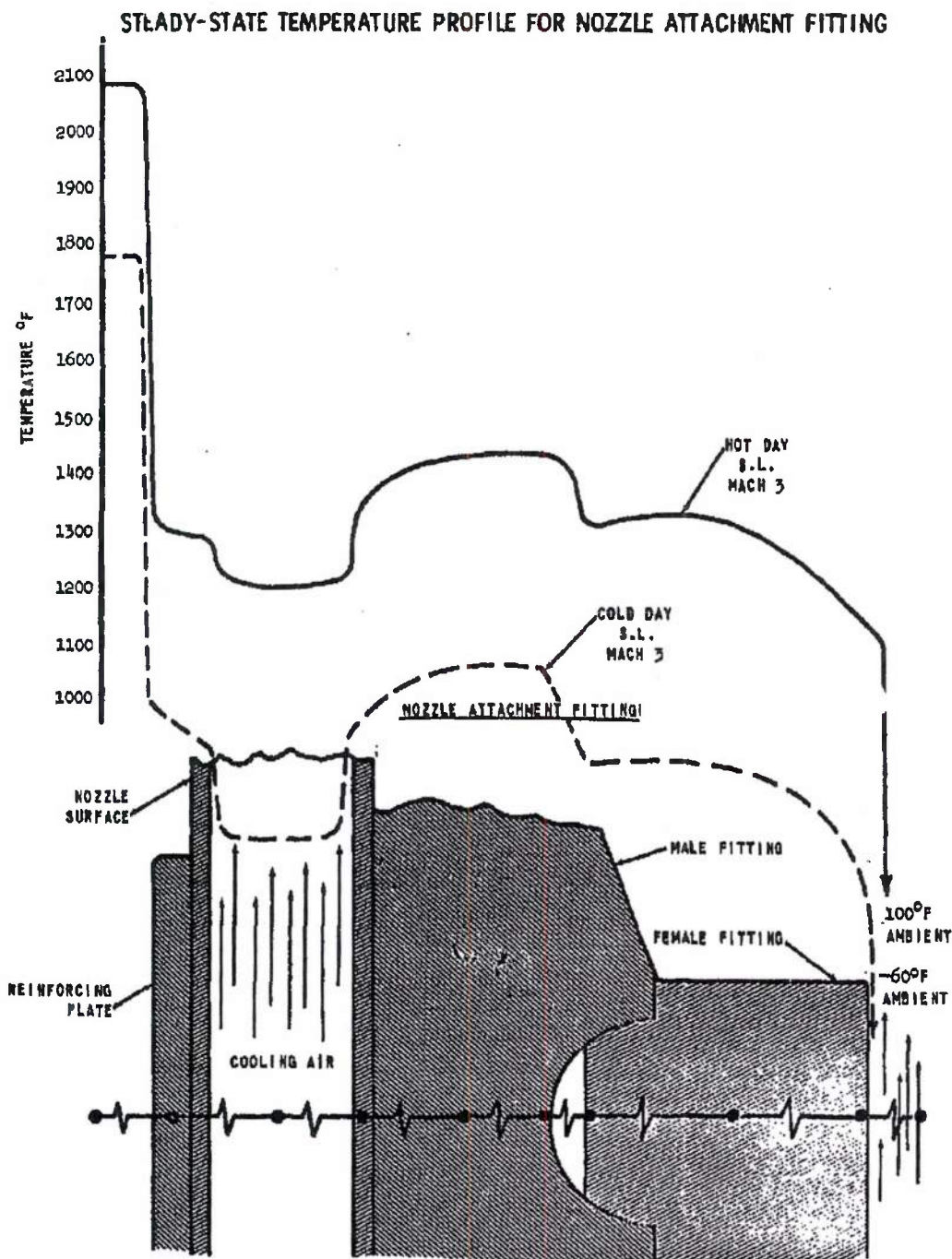
-109-

FIGURE 56

*Marquardt*  
 VAN NUYS, CALIFORNIA

REPORT 5876

UNCLASSIFIED

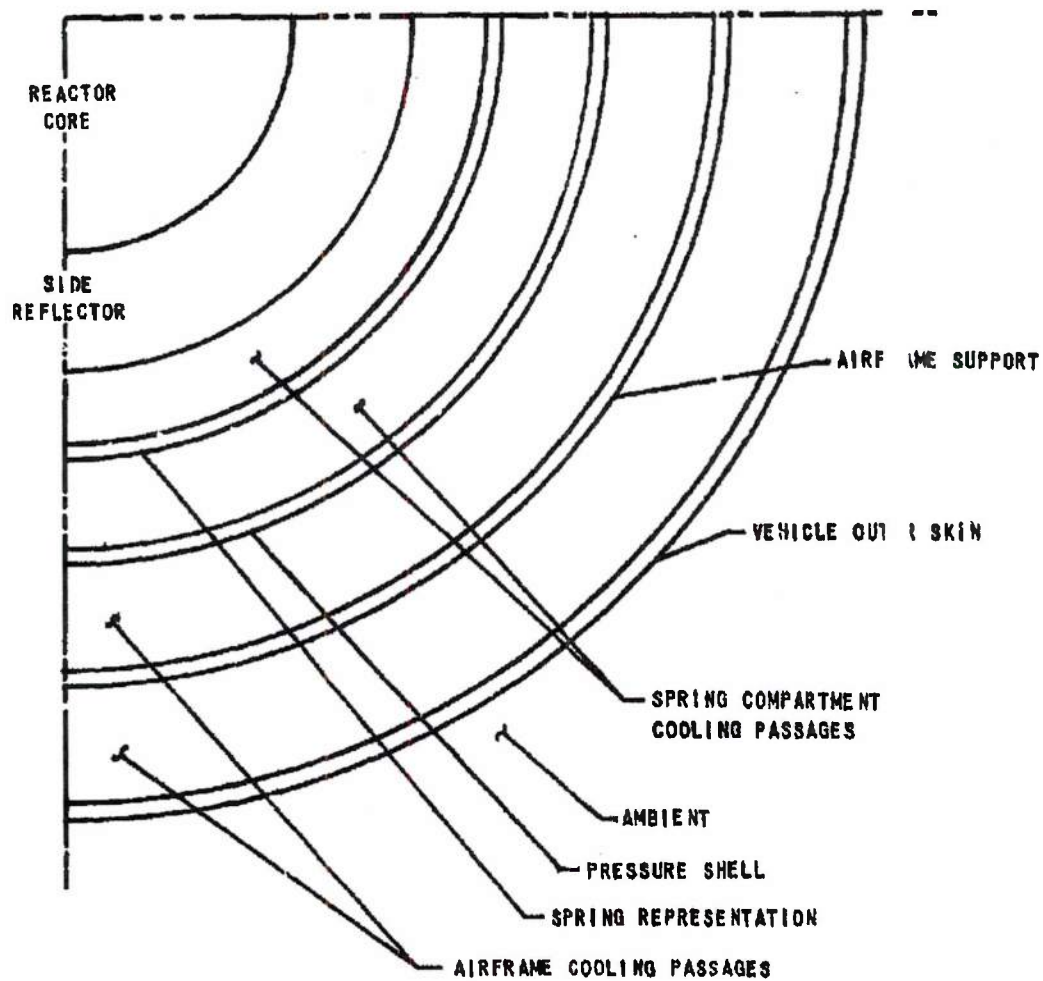


UNCLASSIFIED

THE *Marguardt*  
CORPORATION  
VAN NUYS, CALIFORNIA

ORT 5876

# ANALYTICAL MODEL FOR DETERMINATION OF PROPULSION SYSTEM HEAT REJECTION



Page determined to be Unclassified  
Reviewed Chief, RDD, WHS  
IAW EO 13526, Section 3.5  
Date: MAY 29 2015

MAC 600

22E633 UNCLASSIFIED

-111-

FIGURE 58



~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

A reactor length simulation of this model on the IBM 704 thermal analyzer program was used for computation of the temperatures that were used to determine the heat rejection rates.

Calculations, based on the best estimates of nuclear heat generation in the support system and airframe, were made for design point conditions (Mach 2.8, ANA 421 Hot Day, and an altitude of 1000 feet). With an airflow rate of 113 lb/sec in the support spring compartment, bounded by the reflector and pressure shell, the support springs reached a maximum temperature of about 1120° F. The total cooling airflow rate inside the airframe structure was assumed to be 50 lb/sec. At this flow, the pressure shell reached a maximum temperature of 1180° F, the internal support member in the airframe reached a temperature of 1480° F, and the vehicle skin maximum temperature was 1000° F. A complete temperature distribution is presented in Figure 59. The total heat rejected by the system, i.e., the heat absorbed by the coolant streams, is about 3.0 Mw. A complete breakdown of the heat rejection is presented in Table 3. This information was presented in Performance Bulletin No. 2. (Reference 3)

Recent studies of the Model MA50-XDA propulsion system (larger diameter, shorter length reactor) at design point conditions were also conducted to determine the steady state temperatures and heat rejection rates. Nuclear heat generation rates were calculated at Marquardt. With an airflow rate of 120 lb/sec in the support spring compartment, the support springs reached a maximum temperature of approximately 1360° F. The total cooling airflow rate inside the airframe structure was kept at 50 lb/sec. At this flow the pressure shell reached a maximum temperature of 1280° F, while the internal support member in the airframe reached a temperature of 1510° F. The vehicle skin temperature in this case was about 1000° F. The total heat rejected by this system is about 3.8 Mw. A complete temperature distribution is presented in Figure 60, and a breakdown of the heat rejection is presented in Table 6. This information is presented in Performance Bulletin No. 4, which is an integral part of this report (Section 3.3).

#### Fuel Element Thermal Stress Analysis

The reactor fuel elements are the energy source that produces the thrust of the propulsion system. The transient behavior of these fuel elements and the preservation of their structural integrity have a direct bearing on the performance of the propulsion system. To insure the highest performance possible, studies have been made to adjust reactor power profiles to give the maximum thrust without exceeding a safe beryllia thermal stress limit. In addition, an IBM thermal analyzer program was devised to calculate the transient behavior of a fueled tube.

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

~~SECRET RESTRICTED DATA~~

ONT 5876

ATOMIC ENERGY ACT OF 1954

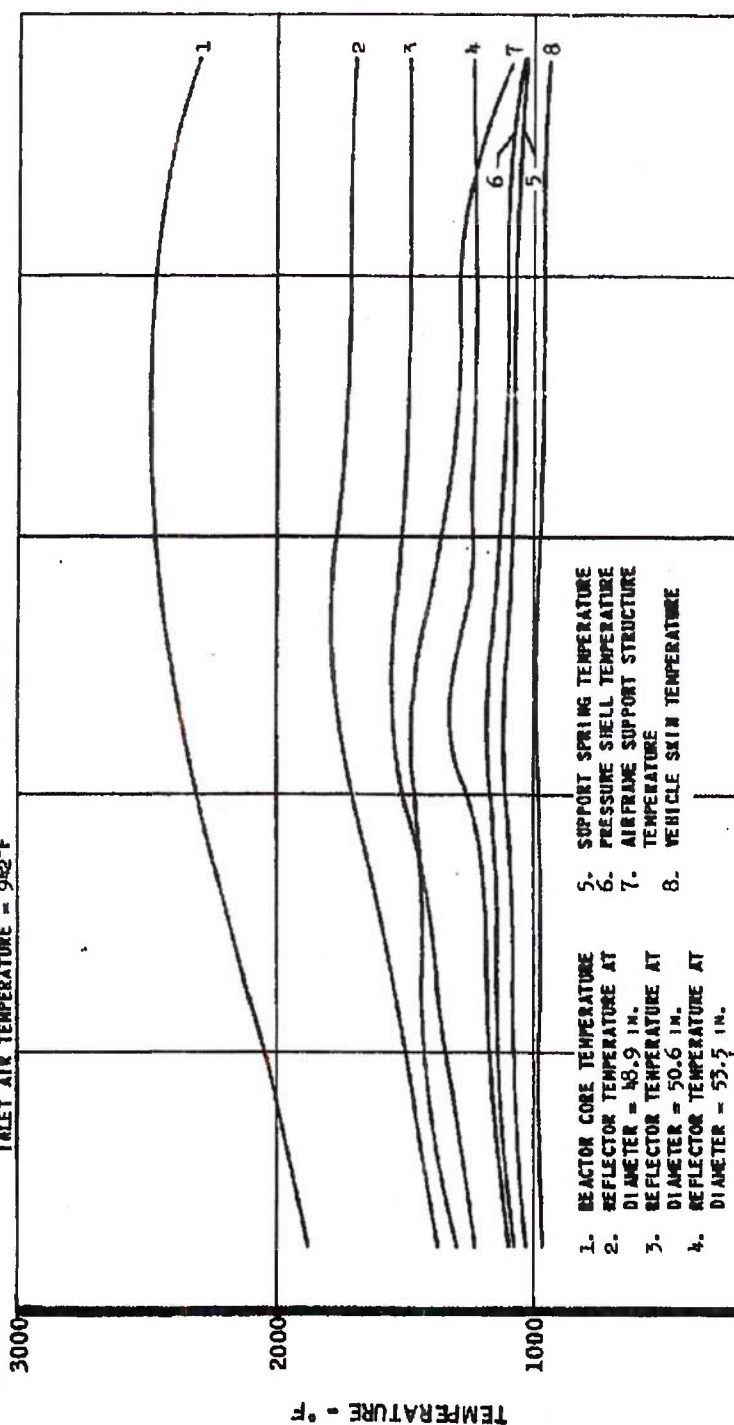
# STEADY-STATE TEMPERATURES IN MA50-XCA PROPULSION SYSTEM AND AIRFRAME

DESIGN POINT CONDITIONS: MACH 2.8; 1000 FT; ANA HOT DAY; REACTOR POWER LEVEL = 516 MW

AIR FLOW THROUGH SUPPORT STRUCTURE = 113 LB/SEC

AIR FLOW THROUGH AIRFRAME = 50 LB/SEC

INLET AIR TEMPERATURE = 942°F



0 10 20 30 40 50  
 DISTANCE FROM FRONT OF REACTOR CORE - in.

MAC AGS

~~SECRET RESTRICTED DATA~~

N22J21 ATOMIC ENERGY ACT OF 1954

~~SECRET RESTRICTED DATA~~

THE *Marquardt*  
CORPORATION  
VAN NUYS, CALIFORNIA

REPORT 58

~~ATOMIC ENERGY ACT OF 1954~~

TABLE 10

HEAT REJECTION OF MA50-XCA PROPULSION SYSTEM  
(Mach 2.8; ANA Hot Day; Altitude, 1,000 feet)

ITEM	Air Flow	HEAT REJECT.			N
	(lb/sec)	(Btu/sec)	(Mw)		
Spring Compartment	113	1845	1.95		4.2
From Side Reflector	--	729	0.77		3.4
From Support Springs	--	628	0.66		2.8
From Pressure Shell	--	488	0.52		7.0
Airframe	50	349	0.37		2.1
From Pressure Shell	--	56	0.06		2.0
From Airframe Support	--	286	0.30		3.9
From Vehicle Skin	--	7	0.01		1.2
To Ambient From Vehicle Skin	--	684	0.72		1.7
TOTAL	--	2878	3.04	1	10.0

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

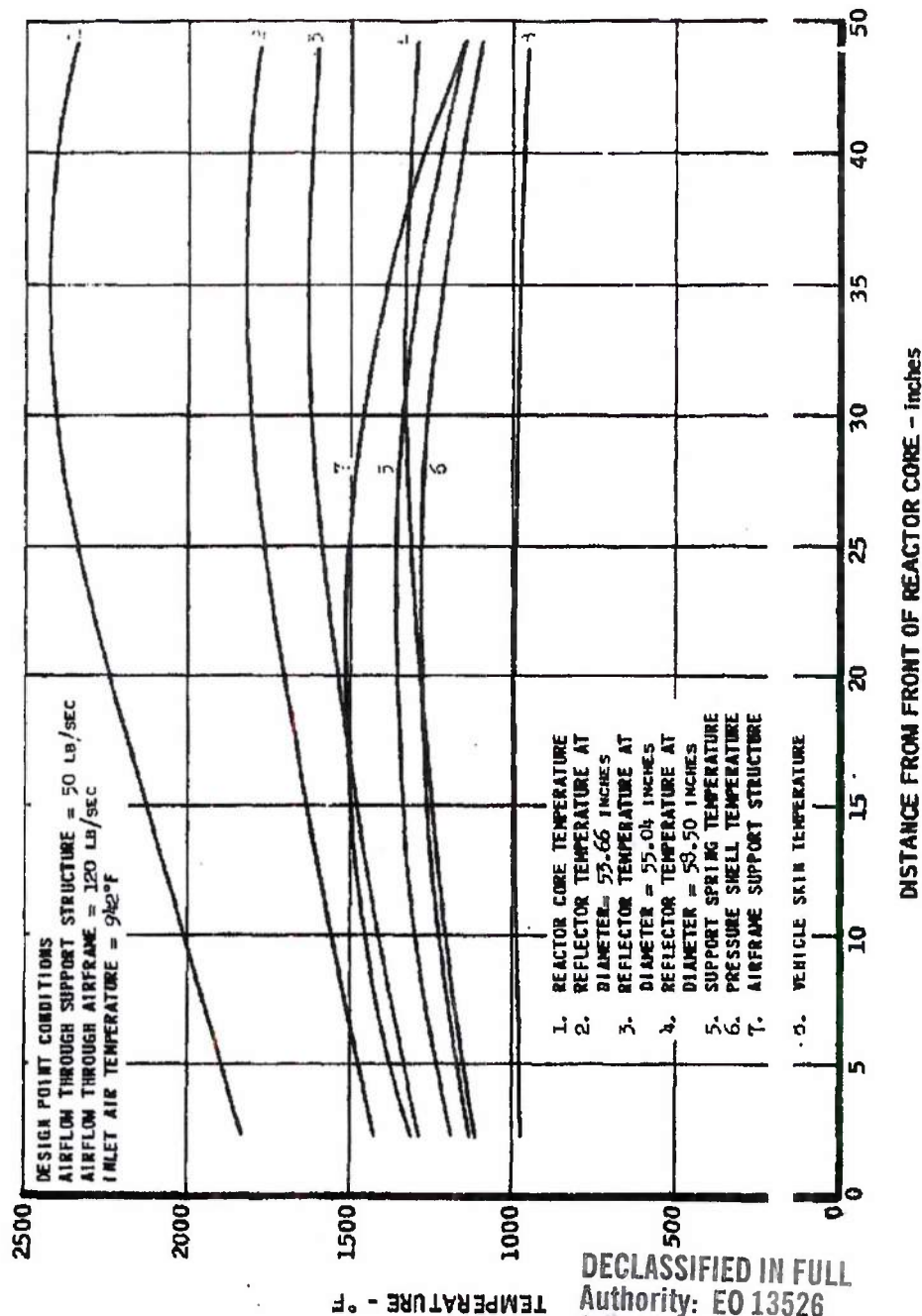
~~SECRET RESTRICTED DATA~~

THE *Marquardt* CORPORATION  
VAN NUYS, CALIFORNIA

REPORT 5876

ATOMIC ENERGY ACT OF 1954

STEADY-STATE TEMPERATURES IN MA50-XDA PROPULSION SYSTEM AND AIRFRAME



DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WIIS  
Date: MAY 29 2015

MAC 400

~~SECRET RESTRICTED DATA~~

N22J16 ATOMIC ENERGY ACT OF 1954

FIGURE 60



~~SECRET-RESTRICTED DATA~~

REPORT 58

~~ATOMIC ENERGY ACT OF 1954~~

### Reactor Fueled Tube Thermal Stress

The steady state elastic thermal stress in a fueled beryllia tube in the Tory IIC reactor has been determined for various power generation and temperature levels. In addition, the temperature difference across the wall of a fuel tube has been determined at the same conditions. Generalized charts of these results are presented in Figures 61 and 62.

These charts were used at Marquardt to revise the Tory IIC reactor axial power curve to produce more thrust. These power curves are based upon a limiting fueled tube thermal stress of 15,000 psi and 18,000 psi, and/or a maximum wall temperature of 2500° F. Figure 40 is a plot of the new power curves along with that for Tory IIC and for a fueled tube with an isothermal wall temperature of 2500° F. From the 15,000-psi thermal stress axial power curve and resultant air and tube wall temperatures obtained from Figures 61 and 62, the maximum elastic thermal stress (tensile) and the maximum temperature in the tube were computed. These results are presented in Figure 63.

### Reactor Fueled Tube Transient Temperatures

An analysis of the effect upon propulsion system performance of such changes in reactor airflow, inlet air temperature, and reactor power has been made possible by the construction of a thermal analyzer program simulating Tory IIC core-length fuel element.

The program will yield the maximum fuel element temperature, wall temperature, outlet air temperature, heat transfer coefficient (based on film temperature), and film temperature for varying air flow rates, inlet air temperatures, and reactor power level. The thermal resistance and capacity of the beryllia fuel element are functions of the fuel element temperature.

This program will be used to assist in the evaluation of transient propulsion system performance at various flight conditions.

### 3.4.3 Control System Support Studies

#### Control Rod Actuator

Preliminary estimates of the steady state temperatures in a flight time control rod actuator were made, for the following flight conditions: Mach 3, ANA Hot Day, an altitude of 1000 feet. In the stationary or nonoperating condition (the most pessimistic condition in the heat transfer sense) with a total

~~SECRET-RESTRICTED DATA~~

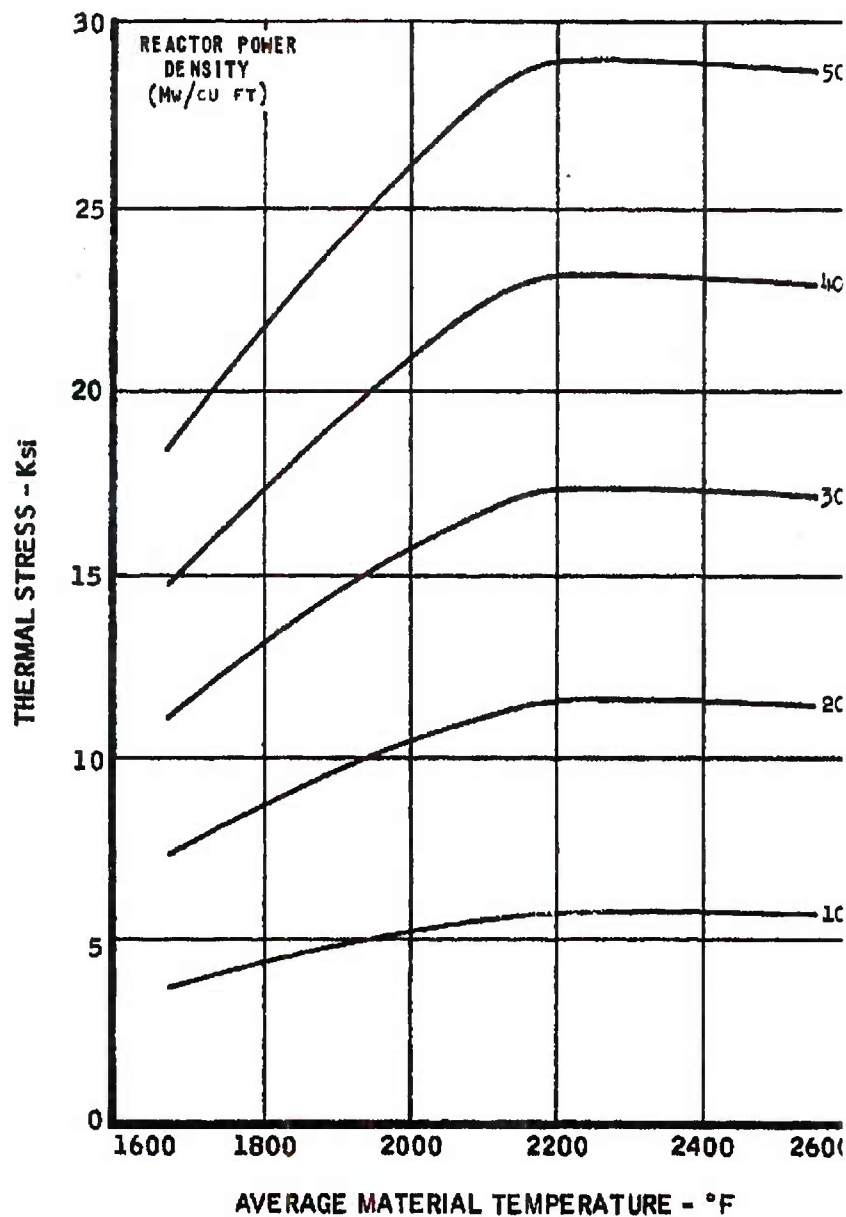
~~ATOMIC ENERGY ACT OF 1954~~

~~SECRET~~

*The Marquardt*  
VAN NUYS, CALIFORNIA

RT 5876

MAXIMUM ELASTIC THERMAL STRESS (TENSILE) IN A TORY IIC FUEL TUBE



N22J20 ~~SECRET~~

-117-

FIGURE 61

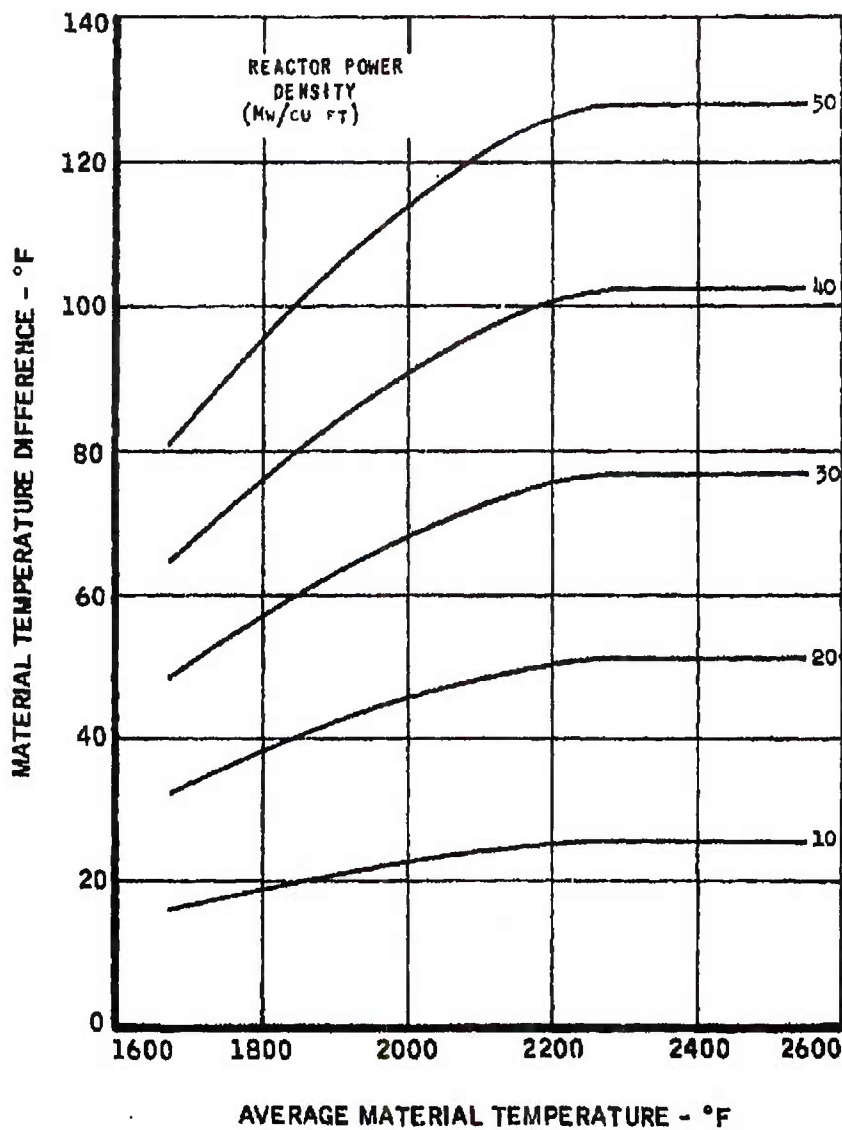
DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHIS  
Date: MAY 29 2015

~~SECRET~~

*The Marquardt*  
VAN NUYS, CALIFORNIA

REPORT 587

### MATERIAL TEMPERATURE DIFFERENCE IN TORY IIC FUELED TUBE



N22J19 ~~SECRET~~

-118-

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WIS  
Date: MAY 29 2015

FIGURE 62

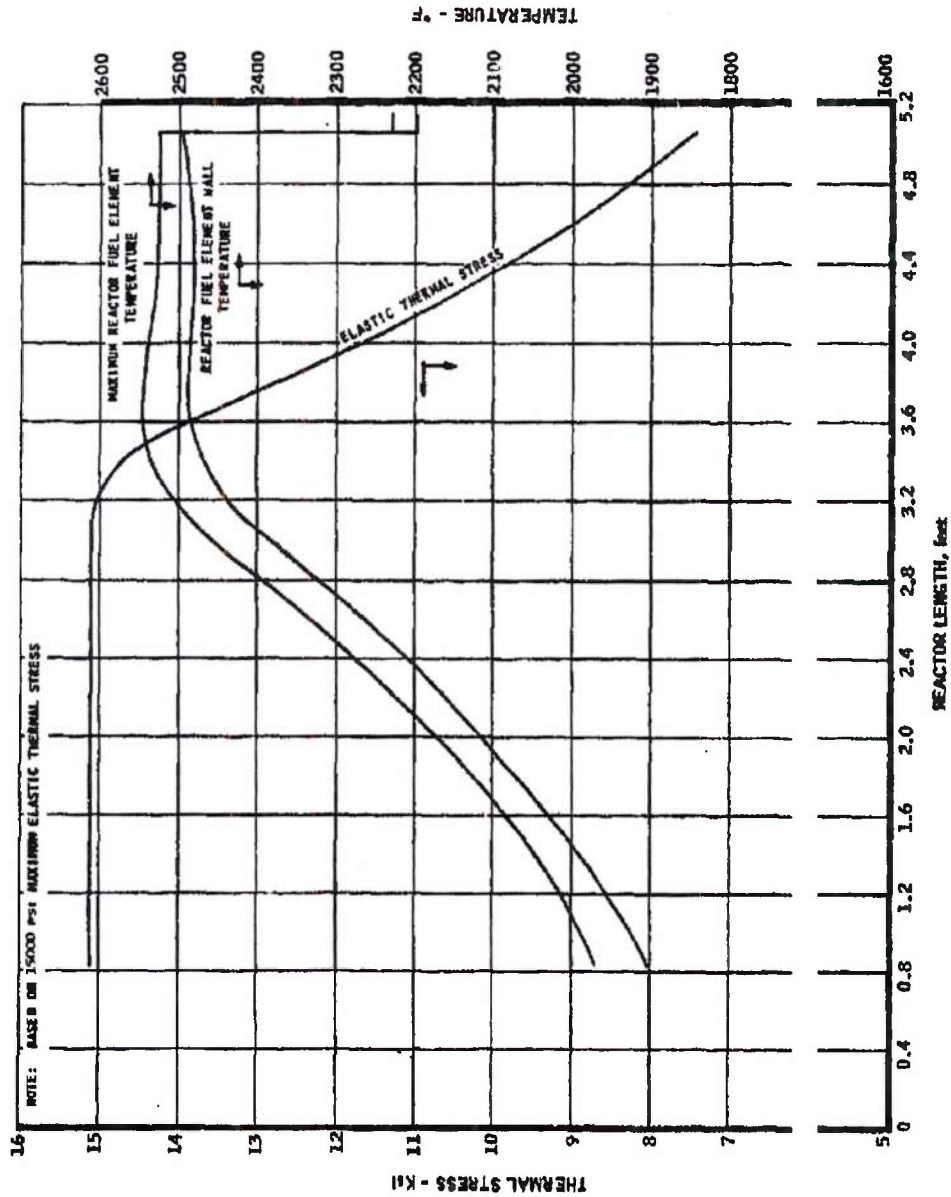
~~SECRET RESTRICTED DATA~~

*The Marquardt Corporation*  
VAN NUYS, CALIFORNIA

REPORT 5876

~~ATOMIC ENERGY ACT OF 1954~~

STEADY-STATE TEMPERATURES AND MAXIMUM ELASTIC THERMAL STRESS  
(TENSILE) IN A TORY IIC FUELED TUBE



DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WIS  
Date: MAY 29 2015

MAC 633

~~SECRET RESTRICTED DATA~~

N22J21 ~~ATOMIC ENERGY ACT OF 1954~~ -119-

FIGURE 63





~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

leakage airflow of 0.04 lb/sec (at 1060° F) through the actuator, the maximum steady state temperature was estimated to be about 1087° F. A complete temperature map is presented in Figures 64 and 65. The temperature limit for the actuator was 1600° F.

The actuator, constructed almost entirely of Stellite 3 and 6B, was assumed to be located in the inlet duct, 60 inches from the reactor front face. The nuclear internal heating of the actuator, due to the attenuation of gamma radiation, is presented in Figure 66. The actuator, one of five, was oriented with its axis perpendicular to the airflow in the inlet duct. The airflow in the 56 inch internal diameter duct is about 1800 lb/sec at 1060° F. All bearings in the actuator were assumed to have an effective void fraction of 0.35.

The IBM 704 thermal analyzer program was used to make the calculations. A program was constructed that may be used for future temperature evaluations. With some modifications, this program may be used for calculation of transient temperatures, consideration of varying thermal properties, etc.

### 3.5 MECHANICAL AND STRUCTURAL DESIGN

The mechanical design effort during 1961 was directed toward the design of an integrated flight type propulsion system incorporating the Tory II reactor. Design layouts of the Model MA50-XCA engine were completed, along with layouts of major engine components.

#### 3.5.1 Engine-AirFrame Integration

##### Lateral Support Structure

In the interests of optimizing the reactor support structure from a performance standpoint - i.e., adequately supporting the Tory IIC reactor inside a minimum diameter airframe - several design concepts have been under investigation. To fulfill its function the reactor lateral support system must properly constrain the reactor core elements, transfer all flight loads to the airframe, accommodate differential thermal expansion between reactor and airframe, and provide the structural support necessary for reactor installation and ground handling.

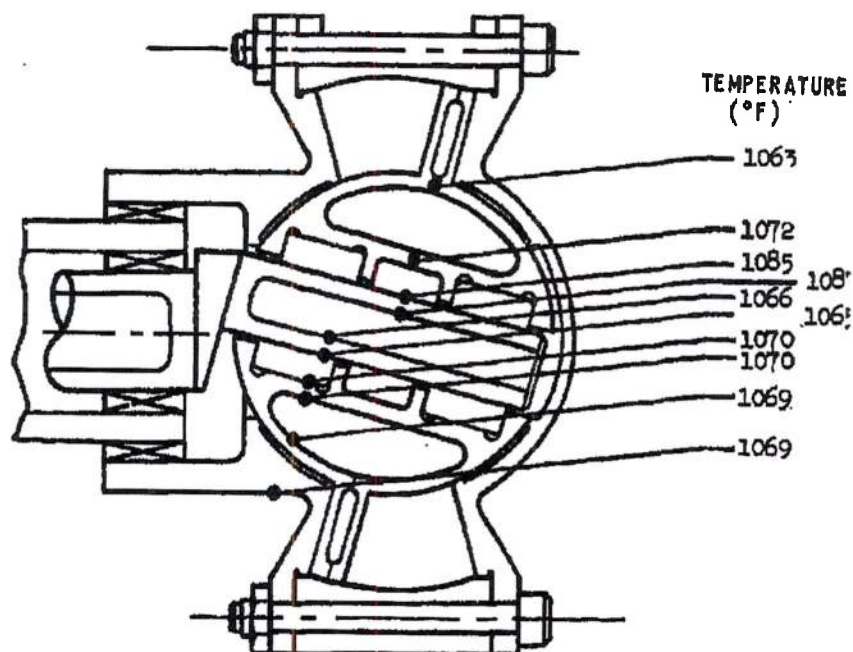
##### Spring Design

Of the methods studied to date, a pre-loaded spring system offers the most effective solution to the reactor support problem. To meet the above

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

# STEADY-STATE TEMPERATURES FOR NUTATING DISK MOTOR OF CONTROL ROD ACTUATOR

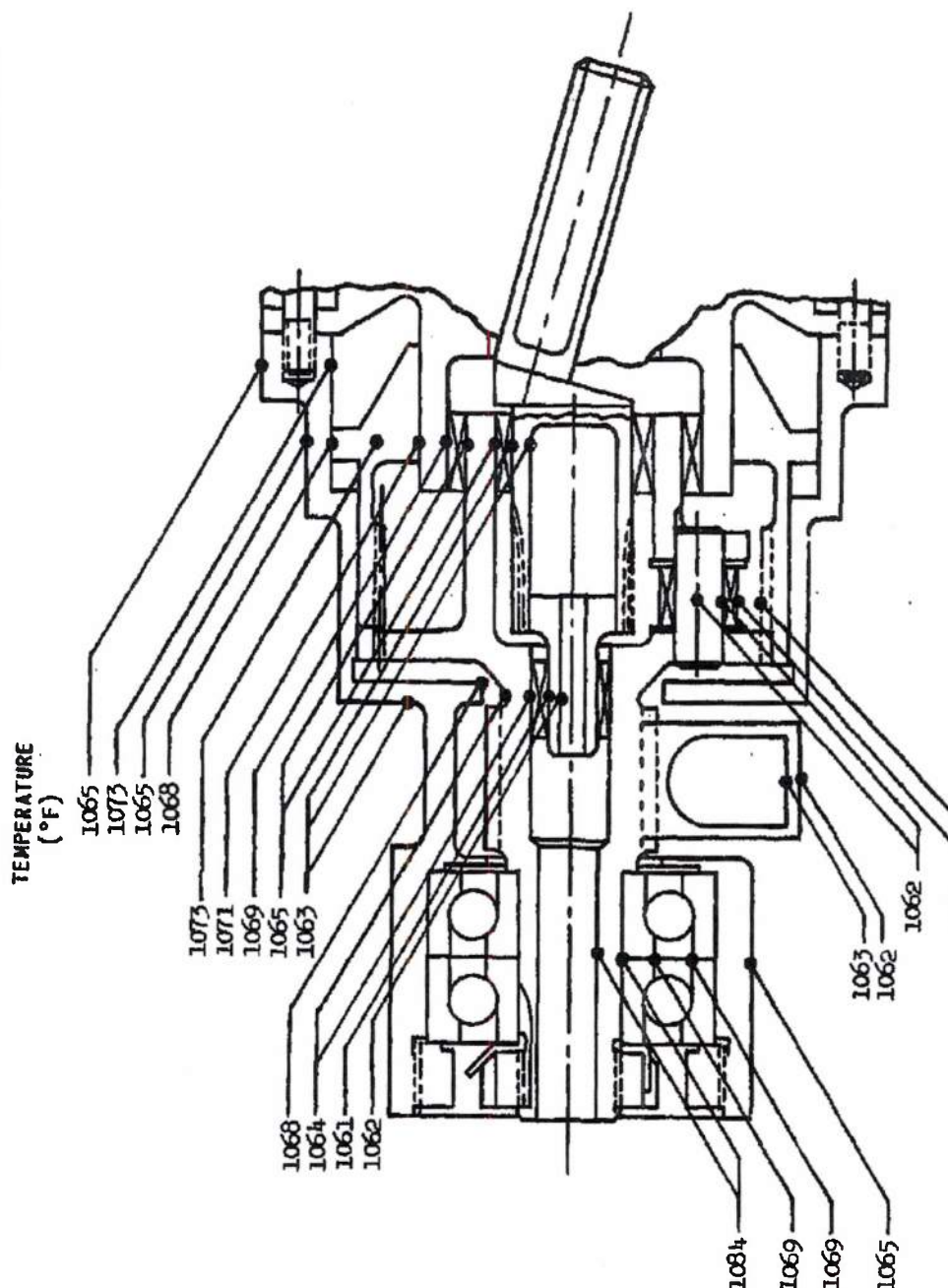


Page determined to be Unclassified  
Reviewed Chief, RDD, WHS  
IAW EO 13526, Section 3.5  
Date: MAY 29 2015

MAC 1578

UNCLASSIFIED

STEADY-STATE TEMPERATURES FOR GEAR TRAIN OF CONTROL ROD ACTUATOR

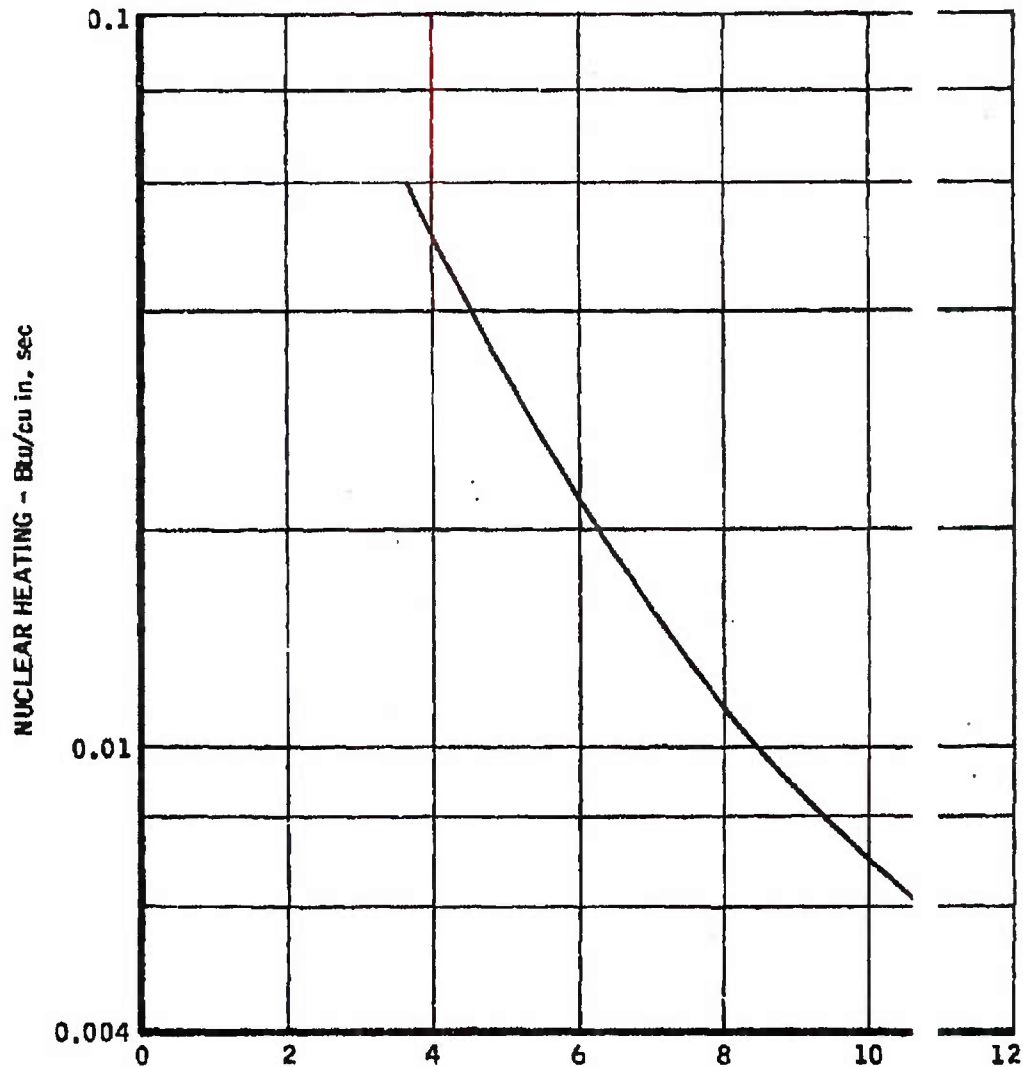


UNCLASSIFIED

*The Marquardt*  
Instrument  
VAN NUYS, CALIFORNIA

OFF 5876

### NUCLEAR HEATING IN CONTROL ROD ACTUATOR



DISTANCE FROM CORE CENTER - feet

Page determined to be Unclassified

Reviewed Chief, RDD, WHS

IAW EO 13526, Section 3.5

Date: MAY 29 2015

MAC 467

N22G589 UNCLASSIFIED

-123-

FIGURE 66

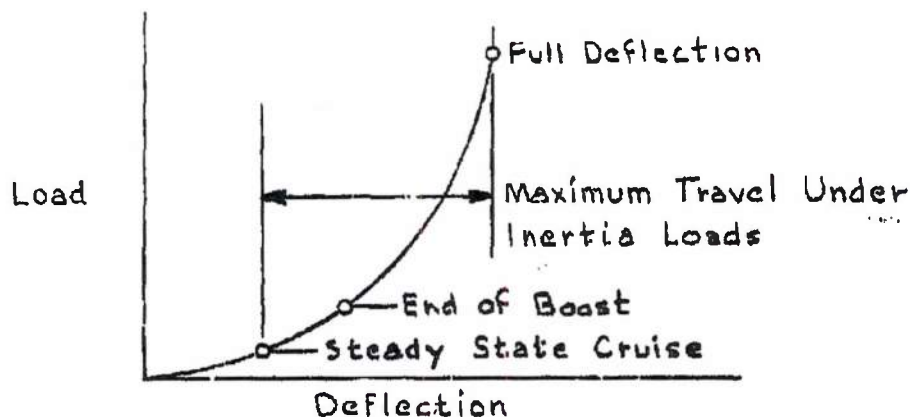


~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

requirements a spring system is needed that has a low load-to-deflection ratio for thermal expansion and a high load-to-deflection ratio when subjected to inertia loads.

The optimum spring should exhibit a nonlinear load deflection as shown below:



Types of springs analyzed include tubular, corrugated, Belleville, and "buggy" configurations (Reference 9). The tubular and corrugated springs exhibited either low load-high deflection or high load-low deflection characteristics that were incompatible with the required nonlinear relationship. The Belleville spring was the only geometry studied that approximated the desired load-deflection characteristics. Figure 67 shows the physical arrangement of the Belleville design; however, final recommendations as to the spring configuration best suited for the ground test engine awaits the outcome of the full scale lateral attachment tests to be performed in 1962.

#### Vibration Studies

Vibration analyses have been performed in an effort to define the dynamic response characteristics of the reactor and associated components. The complexity of the structure precludes a rigorous analysis, but useful design information can be obtained from analyses of idealized models.

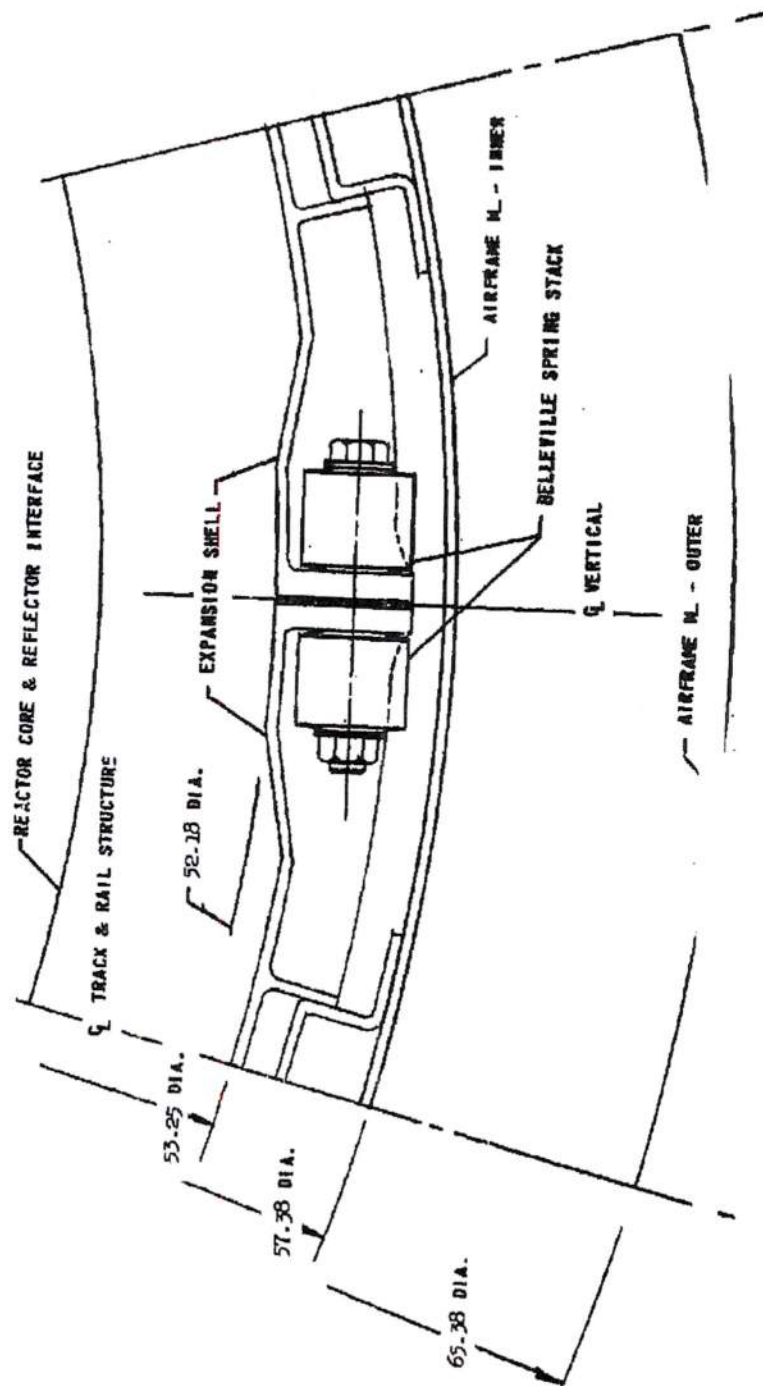
~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

~~SECRET~~

NY 5876

BELLEVILLE SPRINGS IN REACTOR LATERAL SUPPORT STRUCTURE



MAC A630

N2214 ~~SECRET~~

FIGURE 67

~~SECRET RESTRICTED DATA~~  
~~ATOMIC ENERGY ACT OF 1954~~

One such model assumed an inelastic fluid cylinder vibrating in a homogeneous elastic medium. Results of this study as described in References 16 and 8 indicate that appreciable excitation of distortional modes is unlikely in the frequency range of interest (5-30 cps). However, a low frequency resonance could exist corresponding to the rigid body translation mode.

These results suggest another dynamic model that may be used to include the effect of damping on the system. For this model the tangential (Belleville) spring reactor support (Figure 67) is idealized into a single-degree-of-freedom, slip-damped system. The analysis of this system is pointed toward deriving an equivalent static load, which is reacted by the springs. The tangential spring system and its idealized model are illustrated in Figure 68.

Although the model is for tangential springs, it applies equally well to a radial spring support system, requiring only minor modifications in the equations.

The equivalent static load is given as:

$$V = AW\alpha$$

where

A = Amplification factor  
W = Body weight  
 $\alpha$  = Input inertia load factor

Since W and  $\alpha$  have known values, the amplification factor remains to be determined.

The assumptions used are:

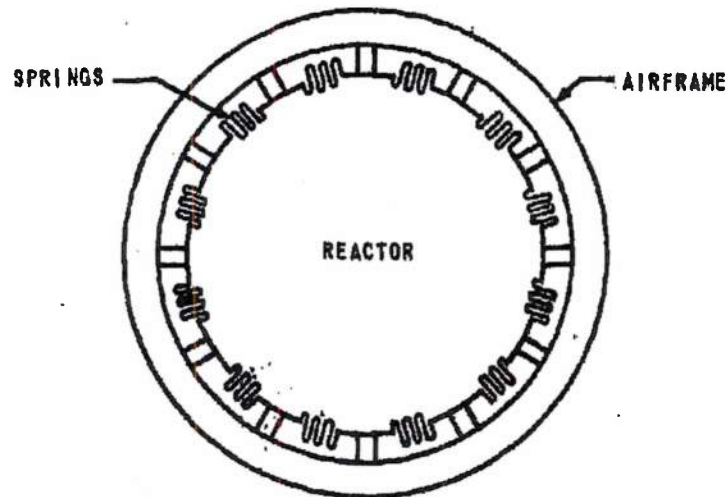
- (1) The airframe surrounding the reactor remains circular.
- (2) The core behaves as a rigid cylinder.
- (3) Only the translational mode is of interest.
- (4) The only damping present results from friction on the periphery of the core.

Assumptions (2) and (3) permit the use of standard derivations (Reference 17) that give the amplification factor as:

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~  
~~ATOMIC ENERGY ACT OF 1954~~

## TANGENTIAL SPRING SYSTEM AND IDEALIZED MODEL



Page determined to be Unclassified  
Reviewed Chief, RDD, WHS  
IAW EO 13526, Section 3.5  
Date: MAY 29 2015



DECLASSIFIED IN FULL

Authority: EO 13526

Chief, Records & Declass Div, WHS

Date: MAY 29 2015



~~SECRET RESTRICTED DATA~~

REPORT 5876

~~ATOMIC ENERGY ACT OF 1954~~

$$A = \frac{1 - \left(\frac{4F}{P}\right)^2}{1 - \frac{f^2}{f_n^2}}$$

where

$f$  = Driving frequency

$f_n$  = Resonant frequency of system

$$\left( f_n = \frac{1}{2} \sqrt{\frac{K_y}{M}} \right)$$

$P$  = Driving force

$F$  = Resisting friction force

The above equation represents an approximate solution of the dry friction damping case.

The driving force is given as:

$$P = W \sin \theta$$

From a static analysis of the load distribution of the system, the equations shown below are found to apply.

The friction force is given as:

$$F = 4\mu R p$$

where

$\mu$  = Coefficient of friction

$p$  = Clamping pressure

$R$  = Radius at which the pressure is applied

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

~~SECRET RESTRICTED DATA~~

POST 5876

~~ATOMIC ENERGY ACT OF 1954~~

Transverse spring constant:

$$K_y = \frac{2h^2}{N} K_c$$

$K_c$  = Spring constant of individual spring  
N = Number of springs

Maximum clamping shell tension and body pressure due to inertia is:

$$T_I = \frac{V}{f_I}$$

$$P_I = \frac{T_I}{R} = \frac{V}{f_I R}$$

With the above dynamic and static equation, coupled with the proper input loads, it is theoretically possible, by adjusting the static pressure and spring constant, to limit the body movements to tolerable amounts. At the same time, the vibrating system can be made relatively independent of frequency by increasing the friction force of the system. Conversely, it may be made independent of friction by keeping the ratio  $f/f_n$  below a critical value. The optimum design represents a compromise between a stiff system, which limits inertial deflections, and a soft spring to accommodate thermal expansions.

There are, in general, three other factors that may give some help. One is, that any excitation of core distortional modes will increase the damping factor. Another is the possibility of reducing the amplification factor at resonance by introducing nonlinearity into the spring design. The third is that the driving vibration is actually highly damped rather than steady state as assumed. The investigation of these parameters will be continued in the future.

#### Engine Weight and Balance

Engine weight and center of gravity (CG) locations have been calculated for the Model MA50-XCA propulsion system using the basic Tory II reactor. The weights of the major engine components and the CG locations are as follows:

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

	<u>Weight (lbs)</u>	<u>Center of Gravity Locations (Engine Station)</u>
Propulsion System	17,806.5	490.47
Inlet	2,197.0	182.59
Diffuser Duct	1,270.0	405.64
Reactor	12,829.4	542.47
Reactor Controls	350.0	445.94
Exhaust Nozzle	1,160.1	604.77

The respective center of gravity locations are shown in Figure 69.

Because there is a possibility that a reactor of larger diameter than the present Tory IIC will be required to provide desired thrust, weight and CG, calculations were performed for reactor configurations having diameters 5 inches and 10 inches larger. Performance optimization studies have also indicated that it may be desirable to reduce the reactor core length. Weight and CG location calculations were made for a variety of reduced reactor lengths. For every 0.1 inch reduction in reactor length, there is a weight reduction of 246 pounds. The results of the diameter and length studies are presented in Reference 9.

### 3.5.2 Engine Inlet and Diffuser

Designs have been completed for the basic inlet (Figure 70) as well as the alternate inlet (Figure 71). Both inlets are underslung, variable geometry, axisymmetric types with S-shaped diffuser duct. Material selections have been made for structural items on the basis of the latest thermodynamic studies that define maximum operating temperatures for various portions of the translating spike and its supporting structure. These temperatures range from 1079° F to 1286° F. The following materials have been selected:

Cowling lip and large structural castings — Haynes Stellite Alloy 31  
Sheet metal structure — N-155 CRES  
Less severely stressed castings in centerbody — Type 347 CRES

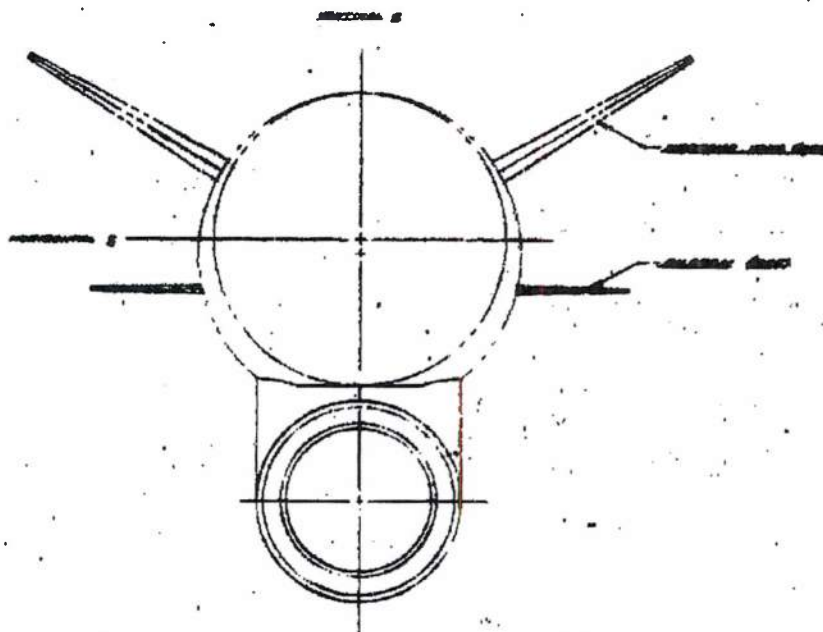
#### Spike Translation

Four methods of inlet spike translation were studied using the following design criteria:

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WIS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~



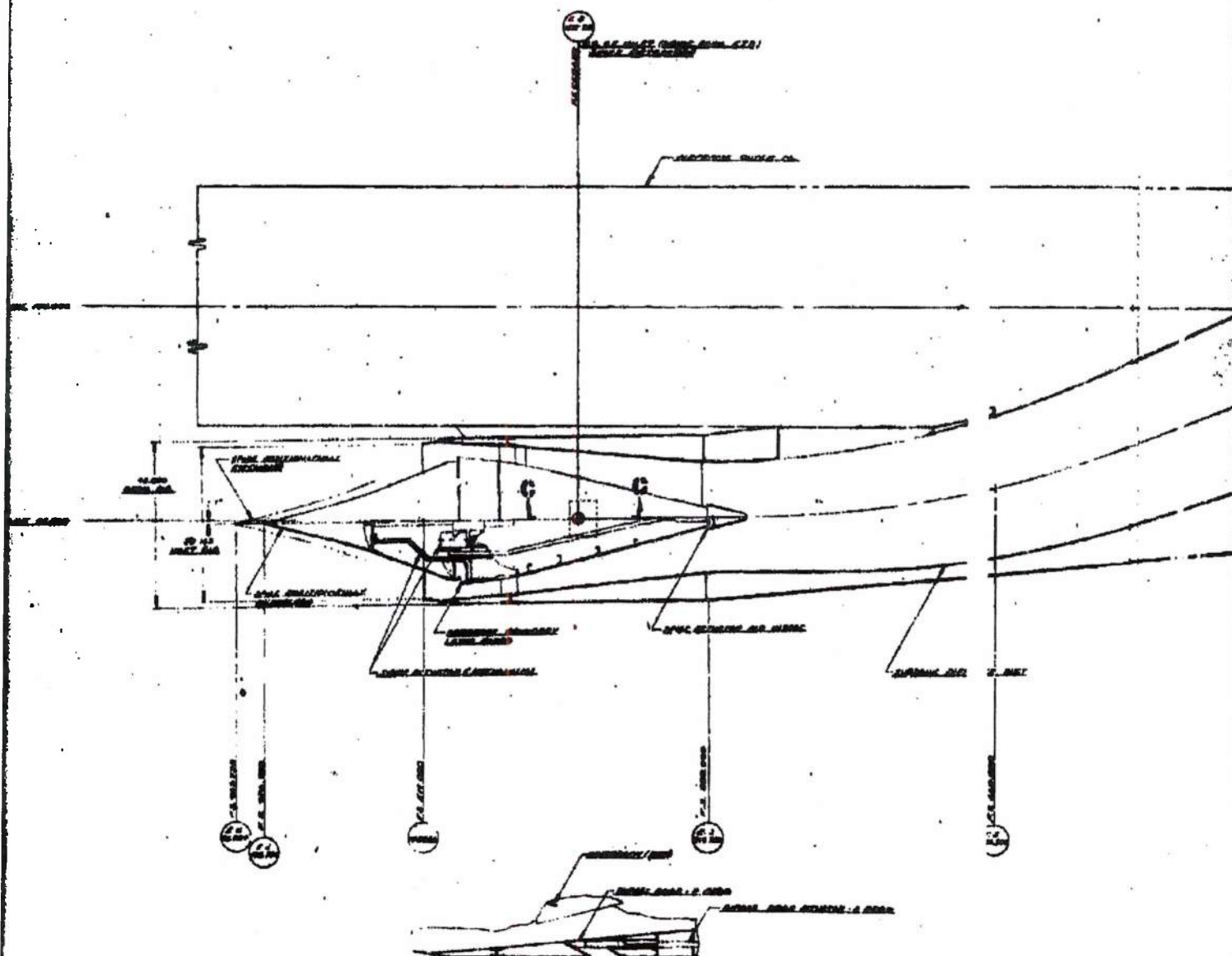
VIEW LOOKING AFT

REPRODUCED FROM  
NAVY DRAWING NO. 1000000000

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015



~~LEADY PROGRAMS - ALL  
LEADS ONLY NOT IN~~



SECTION 6-6

~~SECRET~~

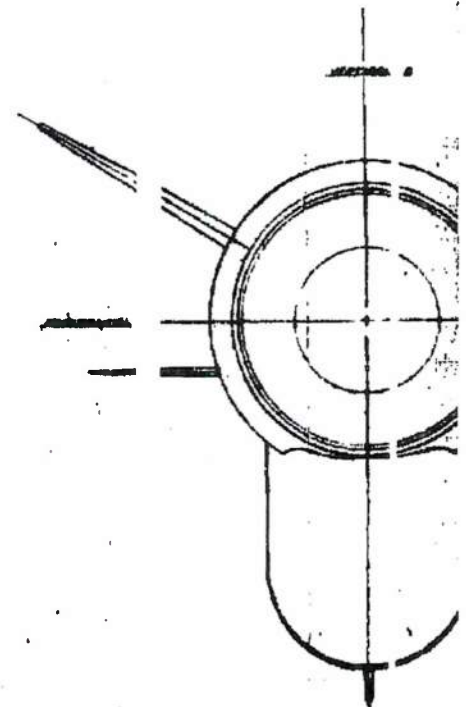
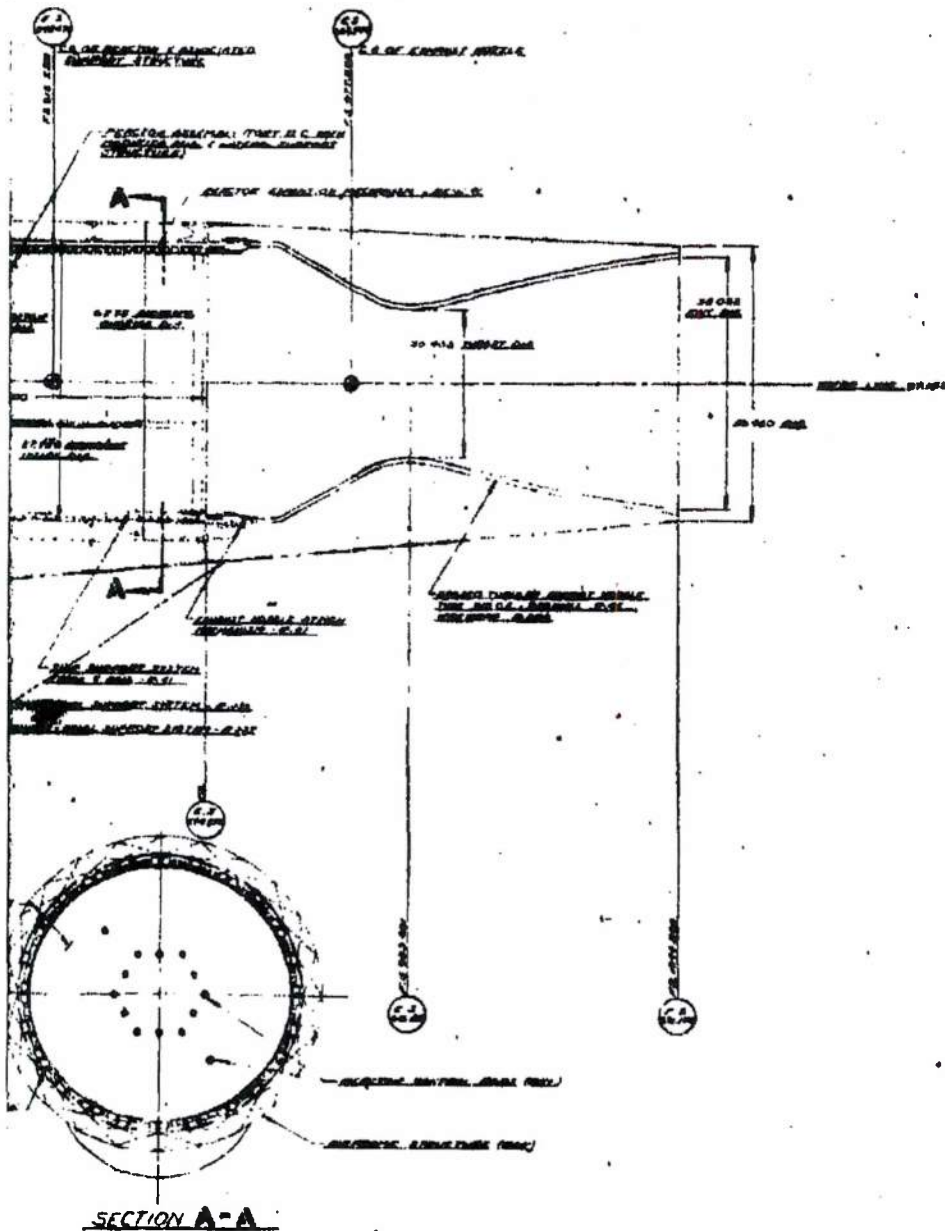
2

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHHS  
Date: MAY 29 2015

~~SECRET~~

3



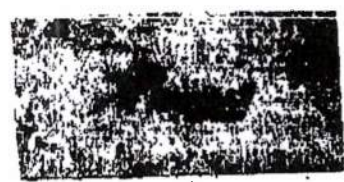


VIEW LOG FILE

~~SECRET - SECURITY INFORMATION~~  
~~TOP SECRET - SECURITY INFORMATION~~

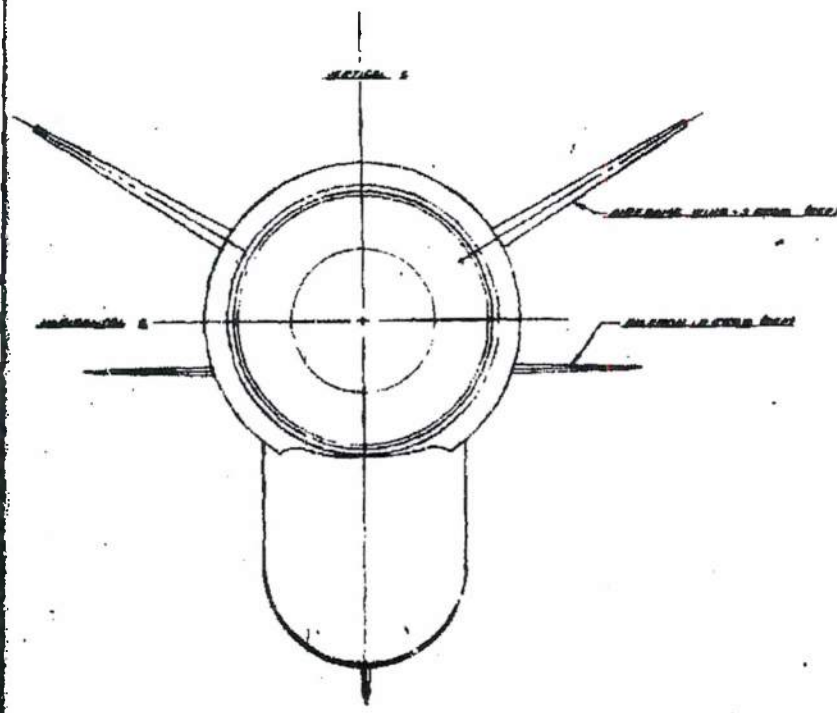
DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WIS  
Date: MAY 29 2015

SECRET - UNCLASSIFIED  
EXCLUDED FROM AUTOMATIC DOWNGRADING AND DECLASSIFICATION



REPORT #276

REPORT #276

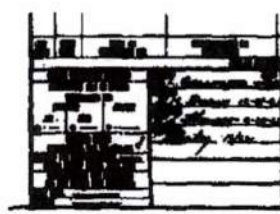


VIEW LOOKING FWD.

PRINTED  
AT THE BUREAU

ED MAY  
7 OF 1964

HARGREAVE STANDARD CO.	
223-9	

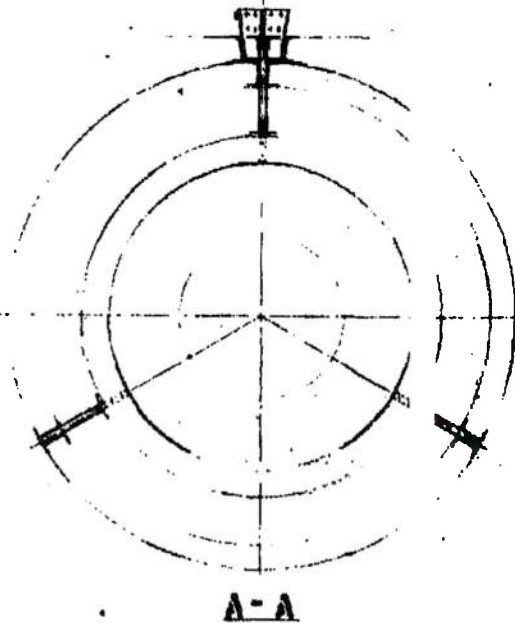
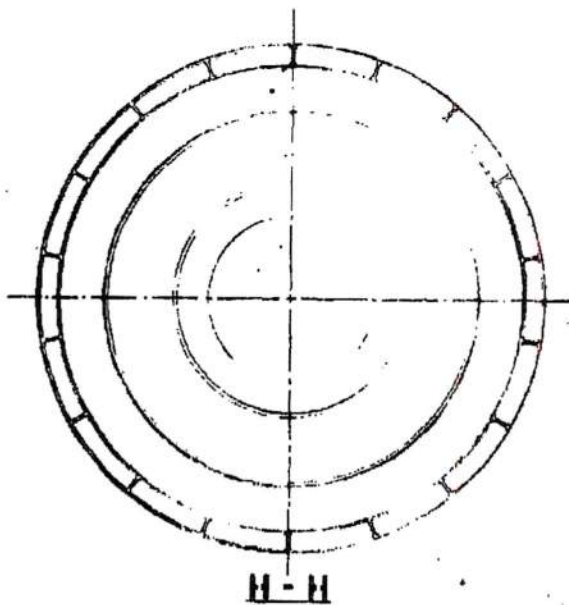


POPULATION SYSTEM	
MASOXCA	
043	X 81381

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WIIIS  
Date: MAY 29 2015

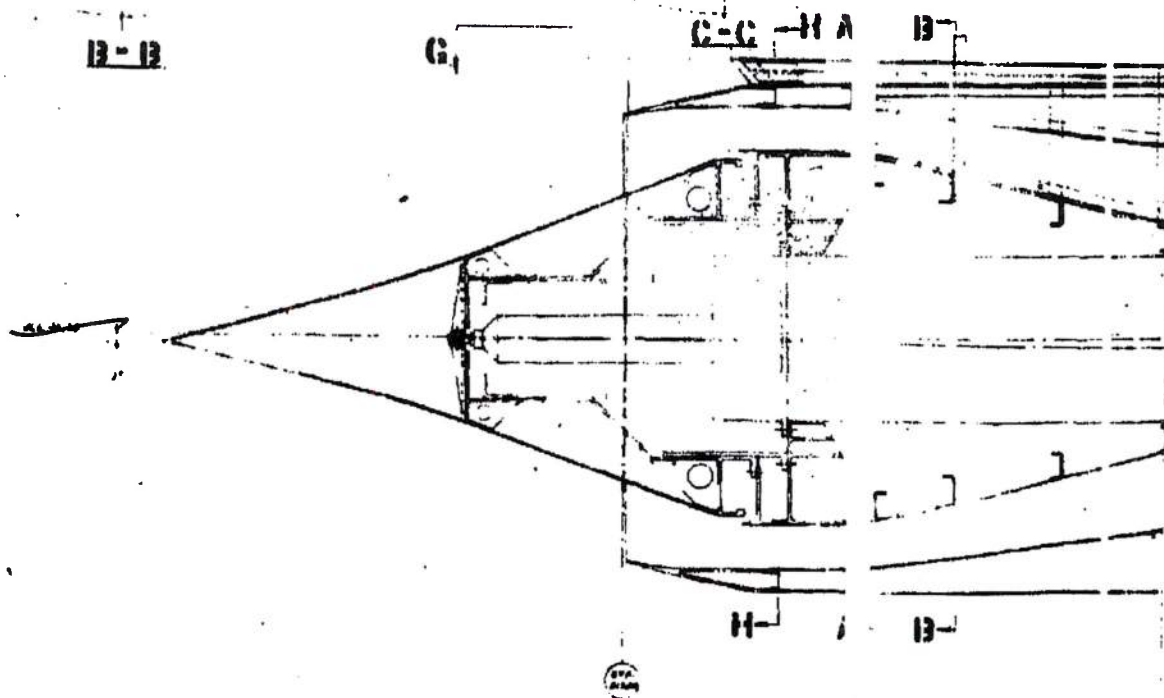
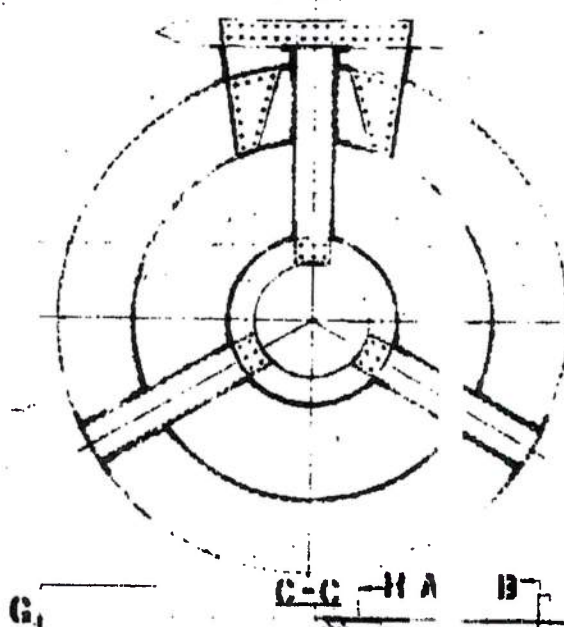
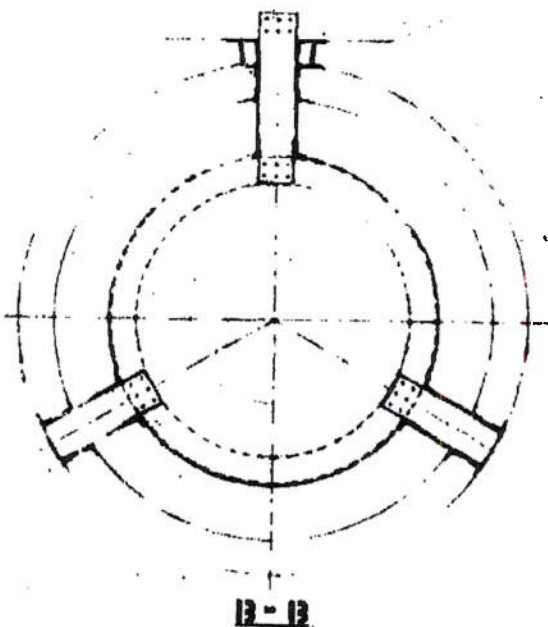


~~SECRET~~



~~SECRET~~

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015



2

DECLASSIFIED IN FULL  
 Authority: EO 13526  
 Chief, Records & Declass Div, WHS  
 Date: MAY 29 2015

~~SECRET~~

APM

G - G

E - E

-E

F -

A- B-

C-

D D-D

A- B-

C-

D-

-E

F-

ST-1000 1000 - 1 1/2 IN. DIA. 100 IN. L.  
LATERAL BY DESIGN OF THE MANUFACTURER, 10-10-10

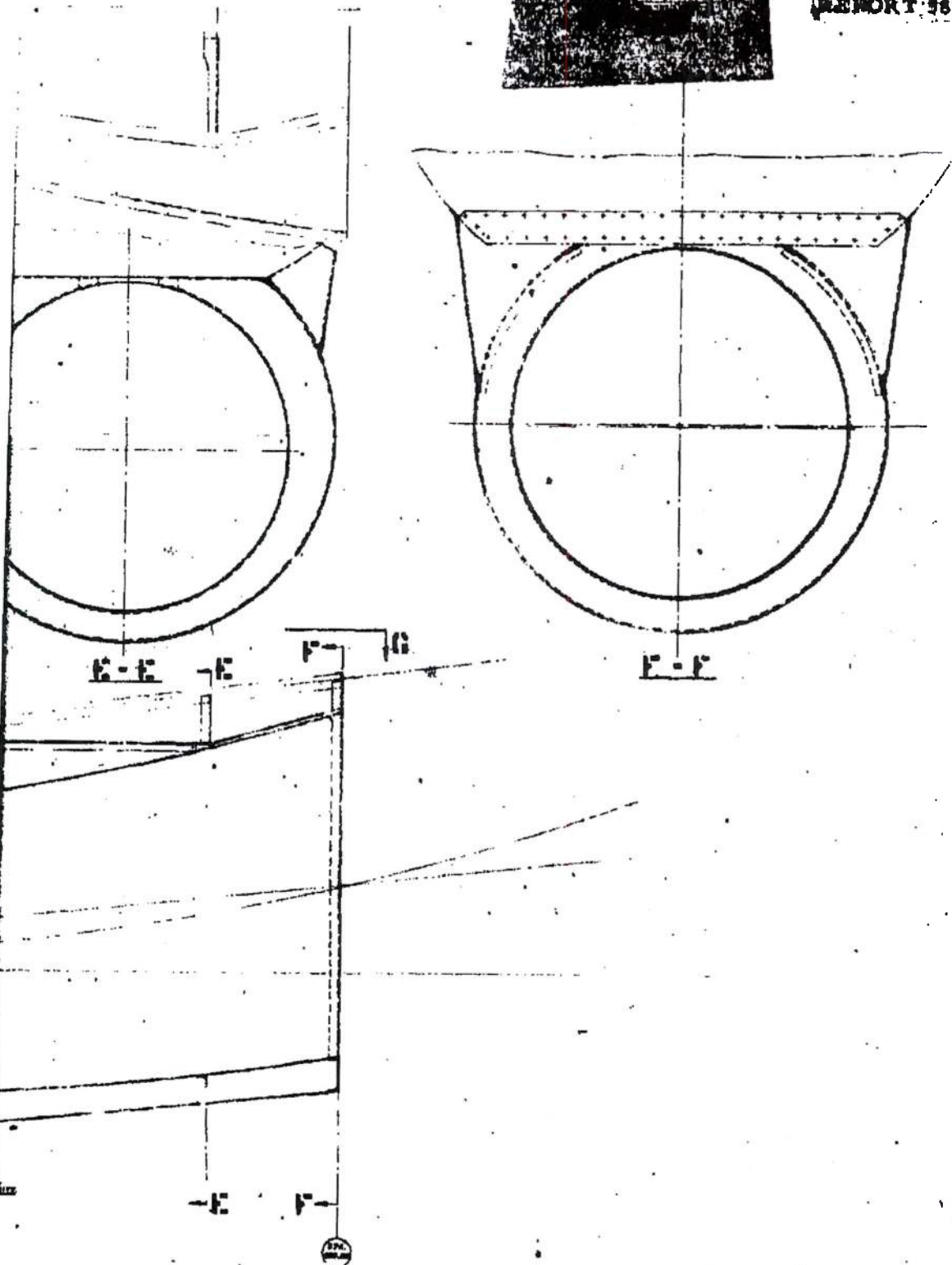
~~SECRET~~

3

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

REPORT 1374

~~SECRET~~



ANISOTROPIC INLET

1327 FIGURE 0

X 81242

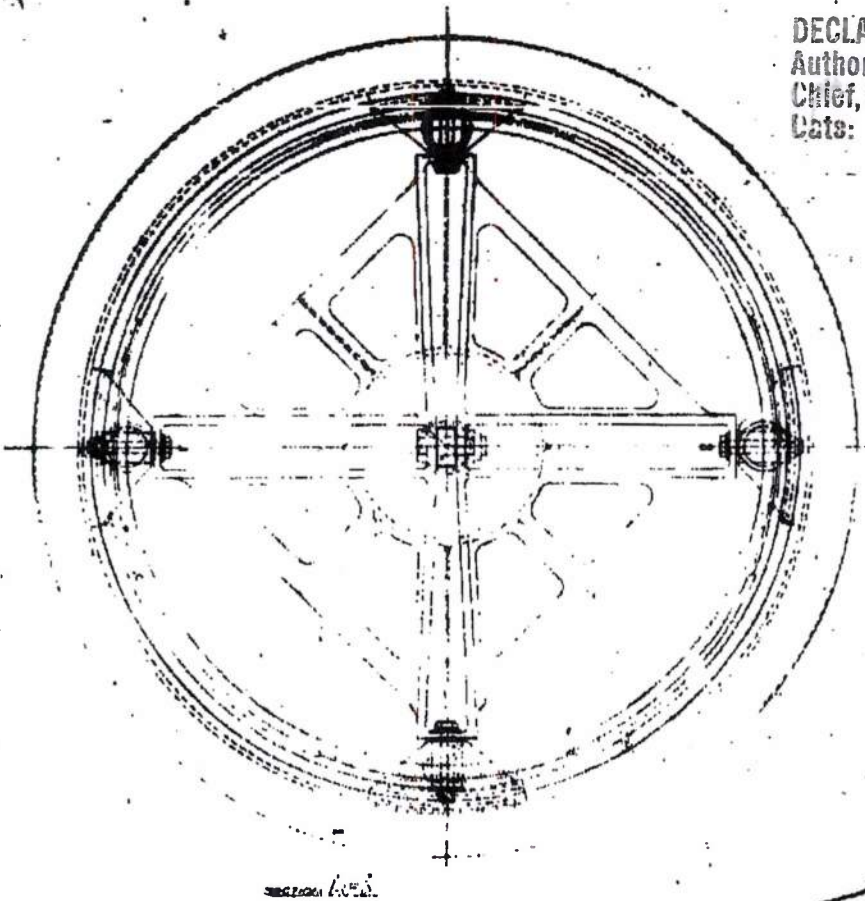
LAYOUT - INL

4 1116 2-11-1

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

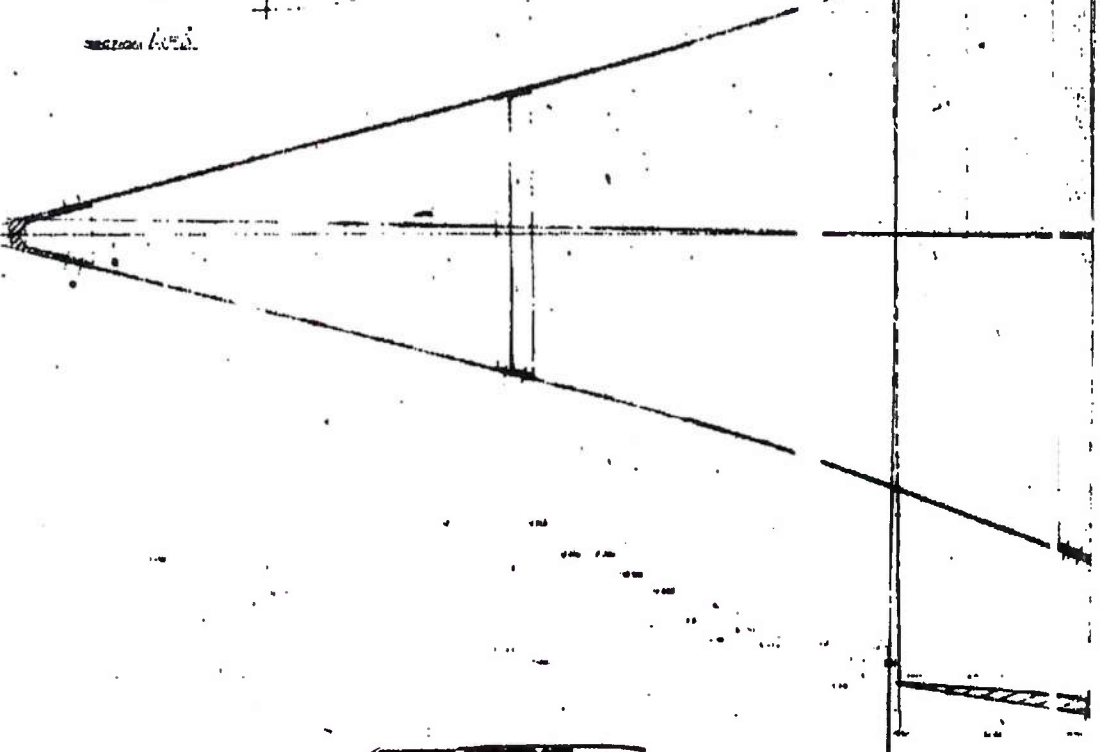


DECLASSIFIED IN FULL  
 Authority: EO 13526  
 Chief, Records & Declass Div, WHS  
 Date: MAY 29 2015



SECTION A-A

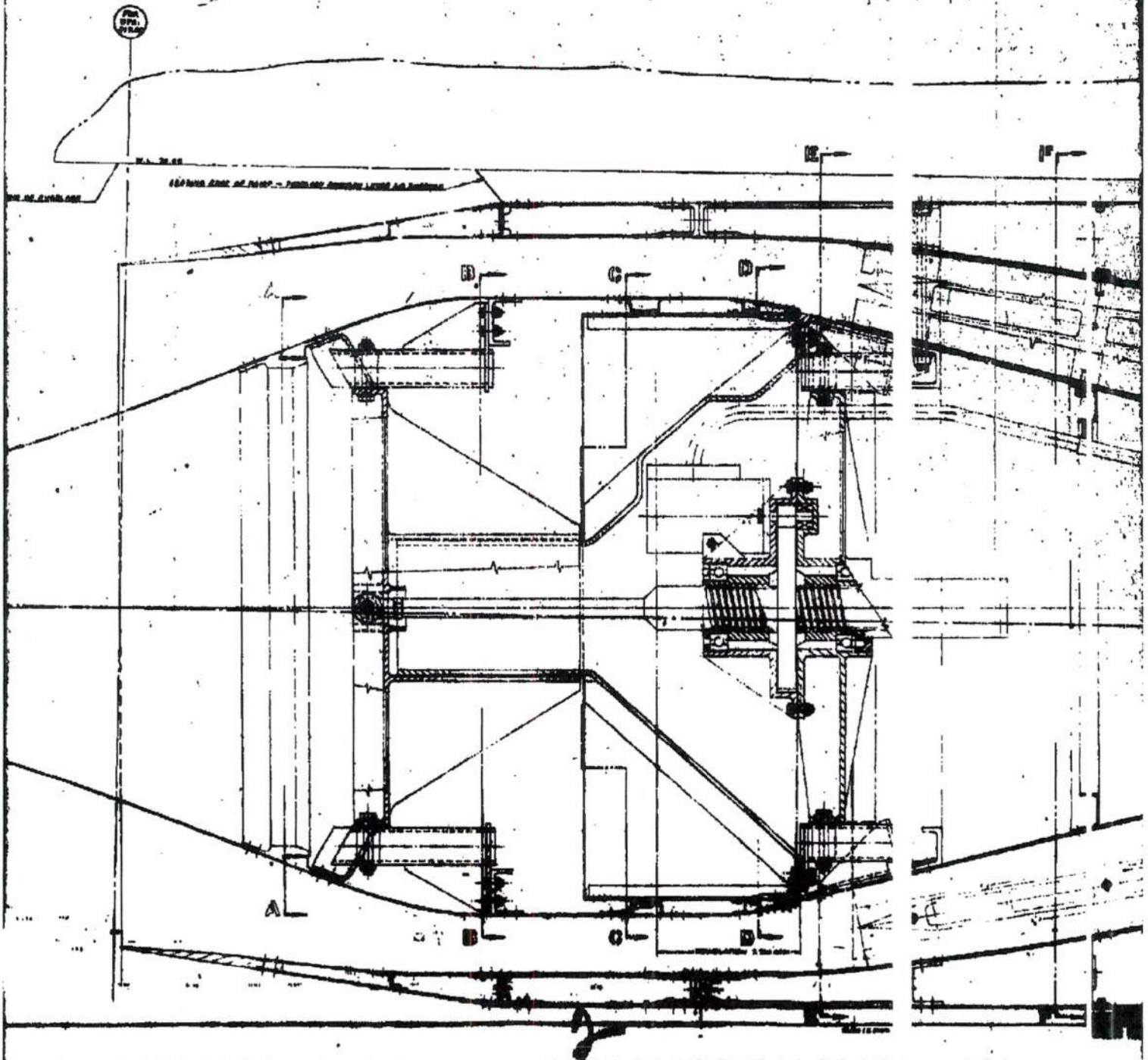
Fig. 96.49



GENERAL NOTES  
 1. SEE FIG. 96.50 FOR DETAILS OF THE HUB AND SPOKES.

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date:

MAY 29 2015



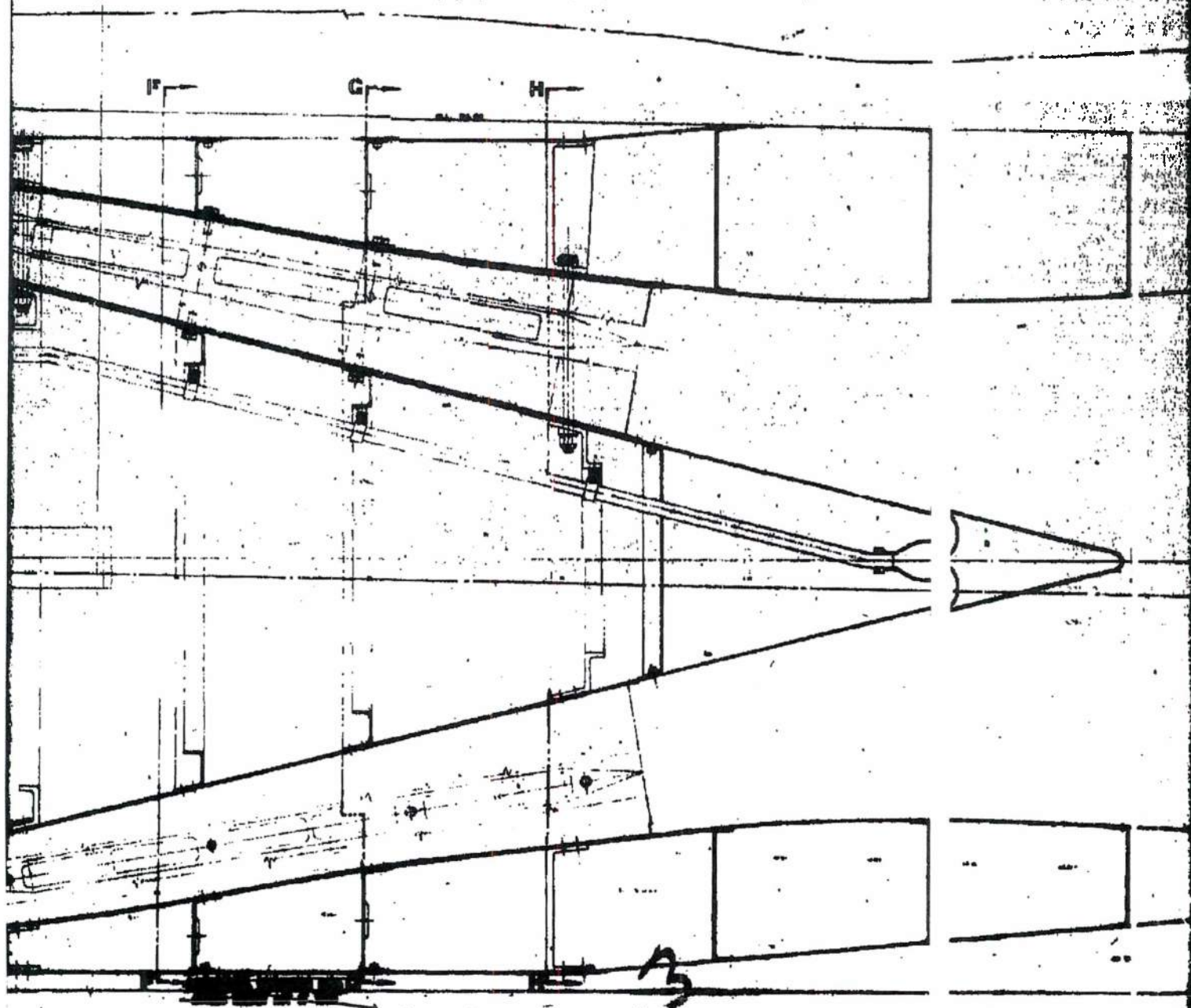


DECLASSIFIED IN FULL

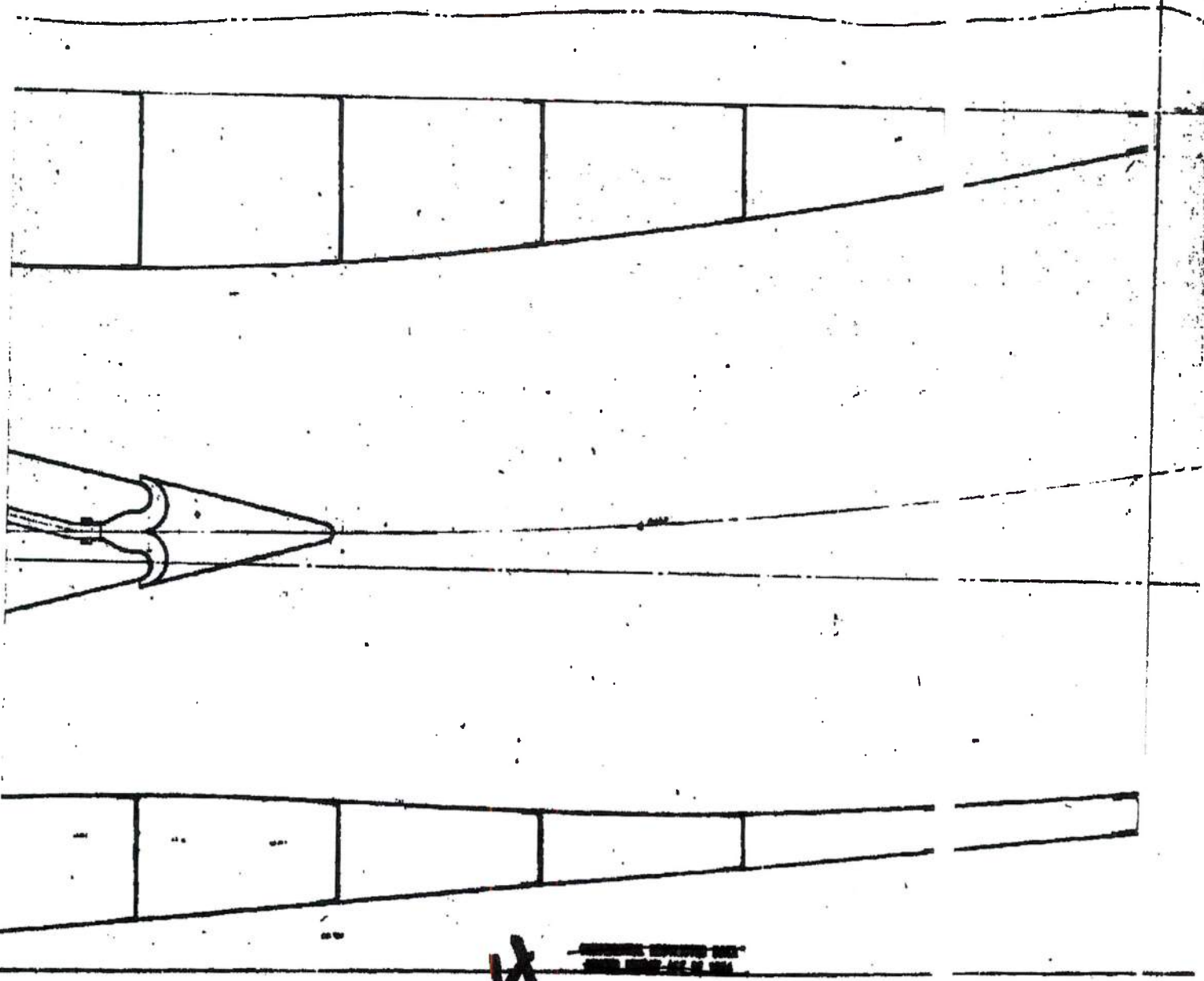
Authority: EO 13526

Chief, Records & Declass Div, WHIS

Date: MAY 29 2015

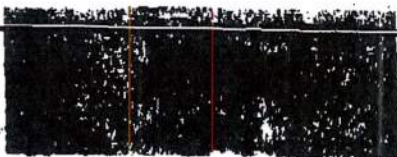


DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015



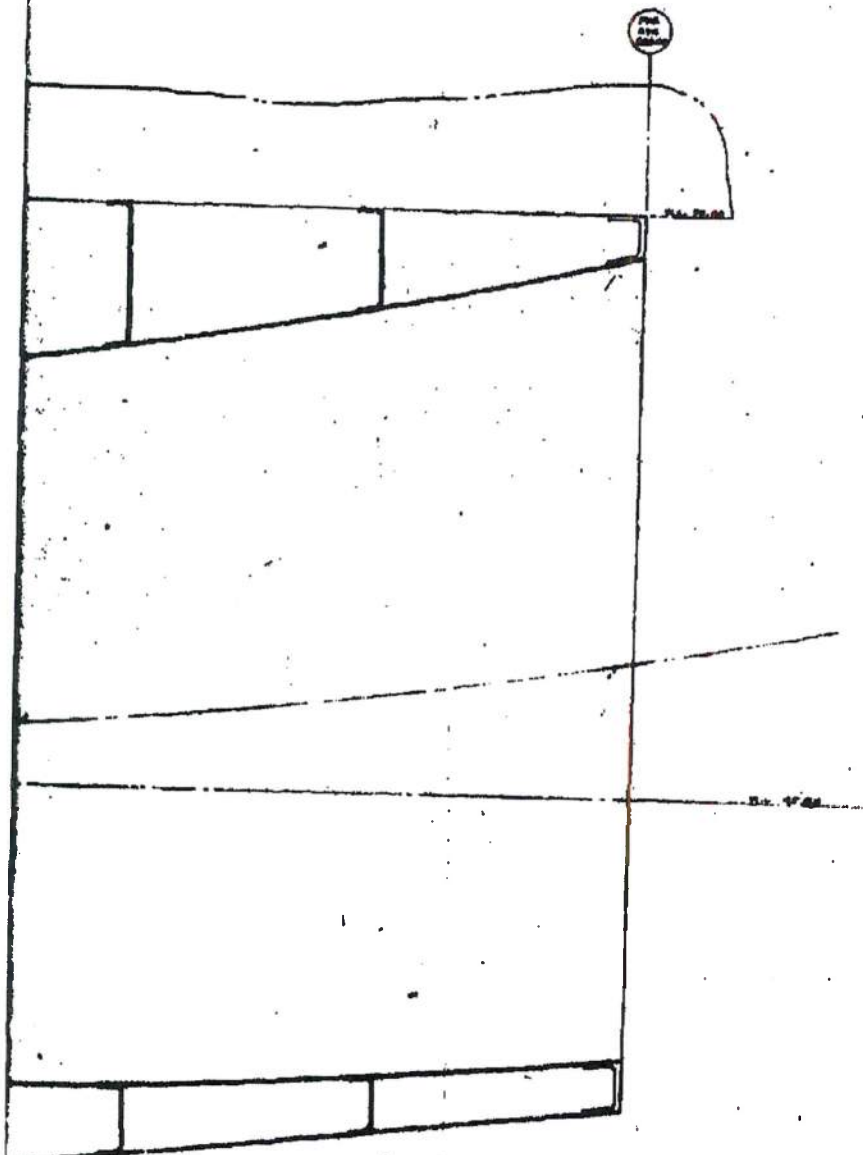
REPRODUCED FROM THE  
OFFICIAL RECORDS OF THE  
U.S. AIR FORCE





SECRET

SECRET



SECRET

SECRET

DATE	1-1-50
BY	1-1-50
REVIEWED	1-1-50
APPROVED	1-1-50
LAYOUT	
1-1-50	
1-1-50	

*Handwritten signature*  
1-1-50

133

FIGURE 73

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

1 5876

~~ATOMIC ENERGY ACT OF 1954~~

Spike load	16,000 pounds
Spike travel	7 inches
Translation rate	7 inches in 6 seconds
Maximum temperature	1200° F

The methods investigated included a rotating nose cone coupled to a rack and pinion system, and a ball screw actuator. In each case, power is supplied by a pneumatic motor. Because of the more evenly distributed masses, thinner wall thicknesses, lighter overall weight, and lower power requirements, the ball screw actuating system has been tentatively selected as the best method of spike actuation. A proposed design is shown in Figure 72.

### 3.5.3 Exhaust Nozzle Design

The exhaust nozzle contour for the flight engine has been established to be a convergent-divergent type, fixed area nozzle. Two configurations have been evaluated for mechanical and structural integrity.

#### Wire-Wrapped Tubular Nozzle

The design for the wire-wrapped tubular nozzle employs a constant perimeter longitudinal tube, die-formed in a convergent-divergent shape. The tubes vary the cross section area in respect to the inner nozzle radius. The tubes are brazed together to form the shell of the nozzle and are then circumferentially wrapped with wire. The wire wrapping is required when the hoop tension loads exceed the allowable tension of the brazed joint between the tubes. Early design studies were based on a coolant airflow rate of 50 lb/sec at 1200° F. The latest information from LRL specifies the coolant airflow rate at 100 lb/sec. This rate dictates a tube size of 13/16-inch outside diameter with a wall thickness of 0.020 inch. A total of 240 tubes of this dimension is required. Each tube is formed into a convergent-divergent shape and flattened into a 1.5° arc. The forward end of each tube makes a transition to a trapezoidal cross section for brazing to the attach ring. This simplifies the machining operation required to mate the tubes to the attach ring.

Maximum gap between parts should not be greater than 0.005 inches if structural reliability of the brazed joints is to be insured.

Studies are being conducted to determine optimum material and possible fabrication problems inherent with this design.

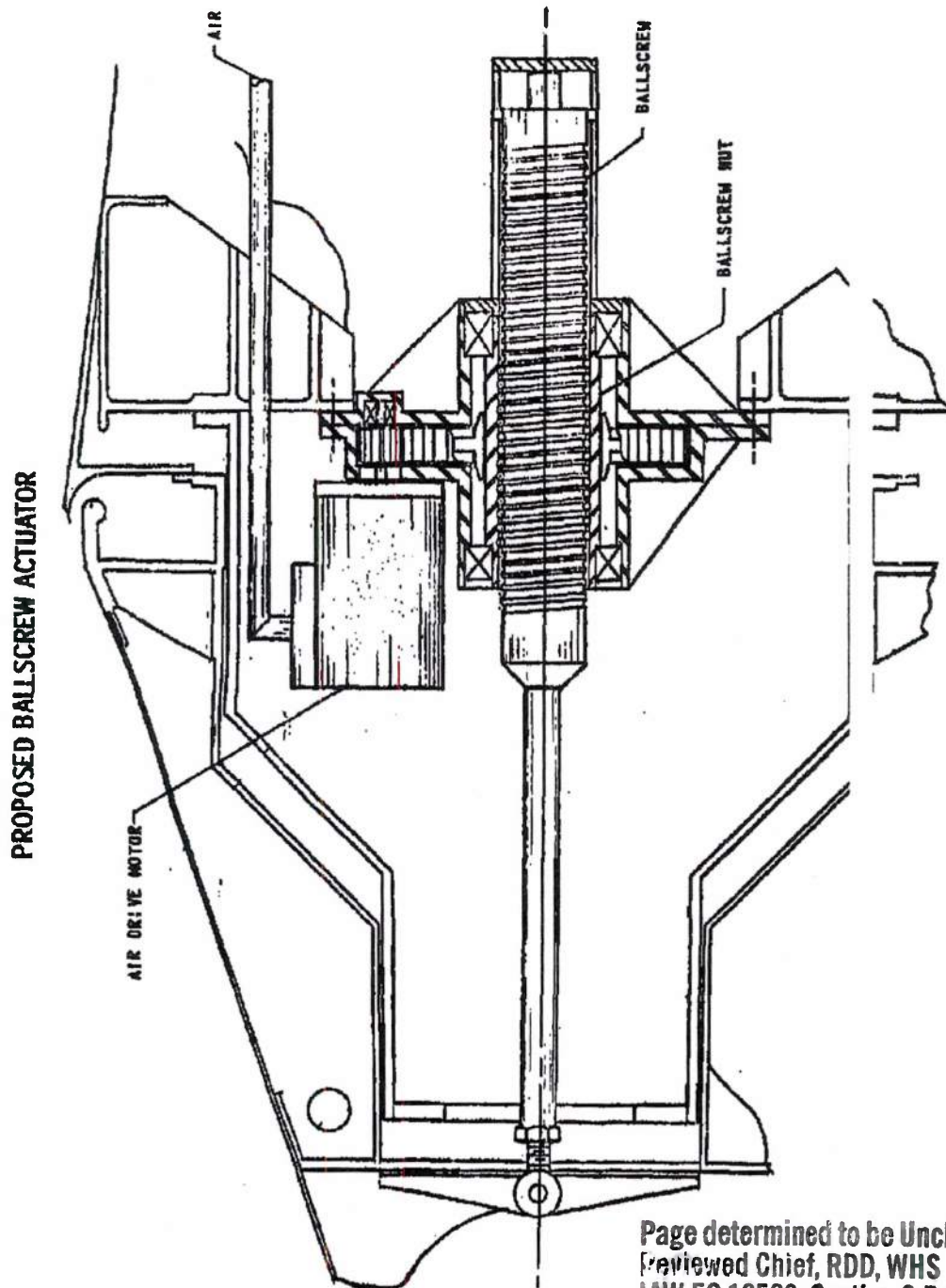
~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

UNCLASSIFIED

*The Marquardt*  
VAN NUYS, CALIFORNIA

NY 5876



Page determined to be Unclassified  
Reviewed Chief, RDD, WHS  
IAW EO 13526, Section 3.5  
Date: MAY 29 2015

22B22 UNCLASSIFIED

-135-

FIGURE 72

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

A preliminary selection of materials is as follows:

Attach Ring - Hastelloy C  
Tubes - R-235 or Rene' 41  
Wire - A286

#### Ejector Nozzle

Preliminary design studies have been completed for the ejector type exhaust nozzle shown in Figure 73.

This design employs a convergent-divergent outer shell with an inner shell in the convergent area only. The annulus between the inner and outer shell is sized such that the engine cooling air will pass through and cool the convergent portion by forced convection. The divergent portion is then film-cooled by the air issuing from the annular passage just aft of the throat.

Preliminary design studies have been based on 0.125-inch thick Rene' 41 material for the two shells.

### 3.6 NEUTRONICS

The threefold objective of the neutronics program has been:

- (1) To increase the performance potential of the basic Tory IIC reactor through parametric studies
- (2) To delineate the mission performance capabilities of the Tory IIC reactor in terms of time effects
- (3) To develop improved analytical techniques and calculation methods

Attempts to extract additional performance from the Tory IIC reactor have involved studies of the effects of increasing the reactor diameter, reducing the reactor length, and modifying the longitudinal reactor power profile.

Time effects studies have been initiated to account for fuel burnup, poison buildup, power profile deviations, and fuel loss, but there is still much work to be done in these areas. The analysis of time effects will be a major item in the neutronics program for 1962.

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~



~~SECRET RESTRICTED DATA~~

ORT 5876

~~ATOMIC ENERGY ACT OF 1954~~

### 3.6.1 Tory IIC Reactor Analysis

Seven complete, two-dimensional studies of the Tory IIC reactor configuration have been completed during the year. The two-dimensional diffusion theory code Angle, developed by the LRL, was used for the analysis. It was of particular interest to investigate design performance, to match design power requirements, and to determine leakage and internal fluxes.

The different studies have assumed a variety of operating temperature levels throughout various regions of the core. Initial studies used temperature regions of 1800, 2100, and 2500° F within the core, with a 1450° F front reflector, an 1800° F radial reflector, and a 2100° F rear reflector. Later studies, for simplicity, represented the core at a constant temperature of 2500° F. Radial power was assumed to be flat in all calculations with the axial power distribution taken from Reference 1. The one-dimensional, 18-group neutronic code Zoom was used to match radial and axial power independently. Predicted fuel distributions were used to obtain initial loadings for the 180 fuel regions for the Angle two-dimensional calculations.

The assumed reactor model has R-235 tie rods as opposed to the LRL design incorporating both R235 and Rene' tie rod materials. The R235 design will require a smaller fuel investment for criticality. The final model studied indicated an effective multiplication factor,  $k_{eff}$ , of 1.03 for a fuel investment of 69 pounds, significantly below the investment required in the Tory IIC design where Rene' tie rods are included.

The geometry and physical data for the final Angle neutronic model of the Tory IIC reactor are shown in Figure 74. Relative power and flux distributions for the 180 core regions considered are shown in Figure 75. The maximum absolute leakage fluxes for each group at the front, side, and rear of the reactor are noted in Figure 76. The energy limits of the 18 groups used in the analysis are shown in Table 11.

Additional studies of the Tory IIC configuration are planned for 1962. A reactor model exactly matching the LRL Tory IIC model will be studied to establish a firm basis for all future comparison studies.

### 3.6.2 Isothermal Wall Version of Tory IIC

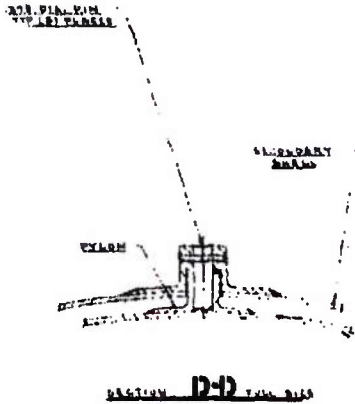
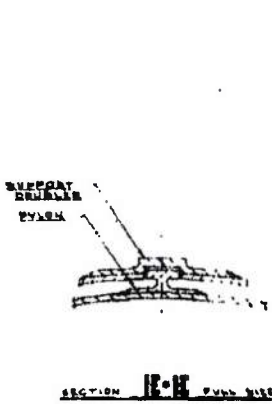
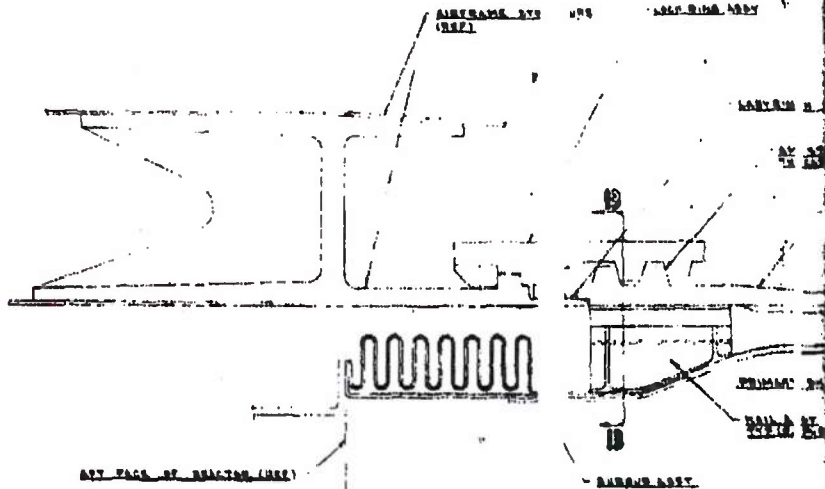
The neutronic feasibility of an isothermal wall version of the Tory IIC reactor was investigated as one possible means of increasing the performance

MAC 407

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

SECRET-NOFORN AND  
OTHER RESTRICTED DATA



DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

SECRET-NOFORN AND  
OTHER RESTRICTED DATA

SECRET-NOFORN AND  
OTHER RESTRICTED DATA

TOP SECRET  
CLASSIFIED

TOP SECRET

AS STRUCTURE

AS STRUCTURE

AS STRUCTURE

AS STRUCTURE

AS STRUCTURE

AS STRUCTURE

AS STRUCTURE

AS STRUCTURE

AS STRUCTURE

AS STRUCTURE

AS STRUCTURE

AS STRUCTURE

AS STRUCTURE

AS STRUCTURE

AS STRUCTURE

AS STRUCTURE

AS STRUCTURE

AS STRUCTURE

TOP SECRET  
CLASSIFIED

TOP SECRET  
CLASSIFIED

2

DECLASSIFIED IN FULL

Authority: EO 13526

Chief, Records & Declass Div, WHS

Date:

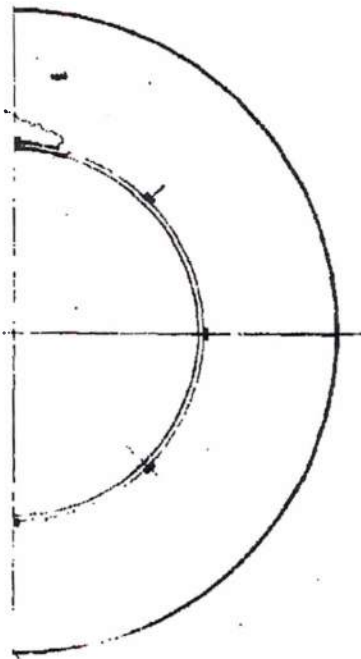
MAY 29 2015







X	Y	Y'
19 00.0	27.5079	20 10.00
5 10.0	27.5178	20 20.00
10 20.0	27.5277	20 30.00
15 30.0	27.5376	20 40.00
20 40.0	27.5475	20 50.00
25 50.0	27.5574	21 00.00
30 00.0	27.5673	21 10.00
35 10.0	27.5772	21 20.00
40 20.0	27.5871	21 30.00
45 30.0	27.5970	21 40.00
50 40.0	27.6069	21 50.00
55 50.0	27.6168	22 00.00
60 00.0	27.6267	22 10.00
65 10.0	27.6366	22 20.00
70 20.0	27.6465	22 30.00
75 30.0	27.6564	22 40.00
80 40.0	27.6663	22 50.00
85 50.0	27.6762	23 00.00
90 00.0	27.6861	23 10.00
95 10.0	27.6960	23 20.00
00 20.0	27.7059	23 30.00
05 30.0	27.7158	23 40.00
10 40.0	27.7257	23 50.00
15 50.0	27.7356	24 00.00
20 00.0	27.7455	24 10.00
25 10.0	27.7554	24 20.00
30 20.0	27.7653	24 30.00
35 30.0	27.7752	24 40.00
40 40.0	27.7851	24 50.00
45 50.0	27.7950	25 00.00
50 00.0	27.8049	25 10.00
55 10.0	27.8148	25 20.00
60 20.0	27.8247	25 30.00
65 30.0	27.8346	25 40.00
70 40.0	27.8445	25 50.00
75 50.0	27.8544	26 00.00
80 00.0	27.8643	26 10.00
85 10.0	27.8742	26 20.00
90 20.0	27.8841	26 30.00
95 30.0	27.8940	26 40.00
00 40.0	27.9039	26 50.00
05 50.0	27.9138	27 00.00
10 00.0	27.9237	27 10.00
15 10.0	27.9336	27 20.00
20 20.0	27.9435	27 30.00
25 30.0	27.9534	27 40.00
30 40.0	27.9633	27 50.00
35 50.0	27.9732	28 00.00
40 00.0	27.9831	28 10.00
45 10.0	27.9930	28 20.00
50 20.0	28.0029	28 30.00
55 30.0	28.0128	28 40.00
60 40.0	28.0227	28 50.00
65 50.0	28.0326	29 00.00
70 00.0	28.0425	29 10.00
75 10.0	28.0524	29 20.00
80 20.0	28.0623	29 30.00
85 30.0	28.0722	29 40.00
90 40.0	28.0821	29 50.00
95 50.0	28.0920	30 00.00
00 00.0	28.1019	30 10.00
05 10.0	28.1118	30 20.00
10 20.0	28.1217	30 30.00
15 30.0	28.1316	30 40.00
20 40.0	28.1415	30 50.00
25 50.0	28.1514	31 00.00
30 00.0	28.1613	31 10.00
35 10.0	28.1712	31 20.00
40 20.0	28.1811	31 30.00
45 30.0	28.1910	31 40.00
50 40.0	28.2009	31 50.00
55 50.0	28.2108	32 00.00
60 00.0	28.2207	32 10.00
65 10.0	28.2306	32 20.00
70 20.0	28.2405	32 30.00
75 30.0	28.2504	32 40.00
80 40.0	28.2603	32 50.00
85 50.0	28.2702	33 00.00
90 00.0	28.2801	33 10.00
95 10.0	28.2900	33 20.00
00 20.0	28.3000	33 30.00
05 30.0	28.3099	33 40.00
10 40.0	28.3198	33 50.00
15 50.0	28.3297	34 00.00
20 00.0	28.3396	34 10.00
25 10.0	28.3495	34 20.00
30 20.0		



1  
 2  
 3  
 4  
 5  
 6  
 7  
 8  
 9  
 10  
 11  
 12  
 13  
 14  
 15  
 16  
 17  
 18  
 19  
 20  
 21  
 22  
 23  
 24  
 25  
 26  
 27  
 28  
 29  
 30  
 31  
 32  
 33  
 34  
 35  
 36  
 37  
 38  
 39  
 40  
 41  
 42  
 43  
 44  
 45  
 46  
 47  
 48  
 49  
 50  
 51  
 52  
 53  
 54  
 55  
 56  
 57  
 58  
 59  
 60  
 61  
 62  
 63  
 64  
 65  
 66  
 67  
 68  
 69  
 70  
 71  
 72  
 73  
 74  
 75  
 76  
 77  
 78  
 79  
 80  
 81  
 82  
 83  
 84  
 85  
 86  
 87  
 88  
 89  
 90  
 91  
 92  
 93  
 94  
 95  
 96  
 97  
 98  
 99  
 100  
 101  
 102  
 103  
 104  
 105  
 106  
 107  
 108  
 109  
 110  
 111  
 112  
 113  
 114  
 115  
 116  
 117  
 118  
 119  
 120  
 121  
 122  
 123  
 124  
 125  
 126  
 127  
 128  
 129  
 130  
 131  
 132  
 133  
 134  
 135  
 136  
 137  
 138  
 139  
 140  
 141  
 142  
 143  
 144  
 145  
 146  
 147  
 148  
 149  
 150  
 151  
 152  
 153  
 154  
 155  
 156  
 157  
 158  
 159  
 160  
 161  
 162  
 163  
 164  
 165  
 166  
 167  
 168  
 169  
 170  
 171  
 172  
 173  
 174  
 175  
 176  
 177  
 178  
 179  
 180  
 181  
 182  
 183  
 184  
 185  
 186  
 187  
 188  
 189  
 190  
 191  
 192  
 193  
 194  
 195  
 196  
 197  
 198  
 199  
 200  
 201  
 202  
 203  
 204  
 205  
 206  
 207  
 208  
 209  
 210  
 211  
 212  
 213  
 214  
 215  
 216  
 217  
 218  
 219  
 220  
 221  
 222  
 223  
 224  
 225  
 226  
 227  
 228  
 229  
 230  
 231  
 232  
 233  
 234  
 235  
 236  
 237  
 238  
 239  
 240  
 241  
 242  
 243  
 244  
 245  
 246  
 247  
 248  
 249  
 250  
 251  
 252  
 253  
 254  
 255  
 256  
 257  
 258  
 259  
 260  
 261  
 262  
 263  
 264  
 265  
 266  
 267  
 268  
 269  
 270  
 271  
 272  
 273  
 274  
 275  
 276  
 277  
 278  
 279  
 280  
 281  
 282  
 283  
 284  
 285  
 286  
 287  
 288  
 289  
 290  
 291  
 292  
 293  
 294  
 295  
 296  
 297  
 298  
 299  
 300  
 301  
 302  
 303  
 304  
 305  
 306  
 307  
 308  
 309  
 310  
 311  
 312  
 313  
 314  
 315  
 316  
 317  
 318  
 319  
 320  
 321  
 322  
 323  
 324  
 325  
 326  
 327  
 328  
 329  
 330  
 331  
 332  
 333  
 334  
 335  
 336  
 337  
 338  
 339  
 340  
 341  
 342  
 343  
 344  
 345  
 346  
 347  
 348  
 349  
 350  
 351  
 352  
 353  
 354  
 355  
 356  
 357  
 358  
 359  
 360  
 361  
 362  
 363  
 364  
 365  
 366  
 367  
 368  
 369  
 370  
 371  
 372  
 373  
 374  
 375  
 376  
 377  
 378  
 379  
 380  
 381  
 382  
 383  
 384  
 385  
 386  
 387  
 388  
 389  
 390  
 391  
 392  
 393  
 394  
 395  
 396  
 397  
 398  
 399  
 400  
 401  
 402  
 403  
 404  
 405  
 406  
 407  
 408  
 409  
 410  
 411  
 412  
 413  
 414  
 415  
 416  
 417  
 418  
 419  
 420  
 421  
 422  
 423  
 424  
 425  
 426  
 427  
 428  
 429  
 430  
 431  
 432  
 433  
 434  
 435  
 436  
 437  
 438  
 439  
 440  
 441  
 442  
 443  
 444  
 445  
 446  
 447  
 448  
 449  
 450  
 451  
 452  
 453  
 454  
 455  
 456  
 457  
 458  
 459  
 460  
 461  
 462  
 463  
 464  
 465  
 466  
 467  
 468  
 469  
 470  
 471  
 472  
 473  
 474  
 475  
 476  
 477  
 478  
 479  
 480  
 481  
 482  
 483  
 484  
 485  
 486  
 487  
 488  
 489  
 490  
 491  
 492  
 493  
 494  
 495  
 496  
 497  
 498  
 499  
 500  
 501  
 502  
 503  
 504  
 505  
 506  
 507  
 508  
 509  
 510  
 511  
 512  
 513  
 514  
 515  
 516  
 517  
 518  
 519  
 520  
 521  
 522  
 523  
 524  
 525

MARQUARDT  
AUGUST 29.  
1940  
22402

245-617-2414  
E.O. 14176-91

NO 2719 A55X  
E 16 10R  
X01300

FIGURE 73

~~CONFIDENTIAL~~

DECLASSIFIED IN-FULL--  
Authority: EO 13526  
Chief, Records & Declass Div, WIIIS  
Date: MAY 29 2015

**THE UNIVERSITY OF CHICAGO**

- 138 -

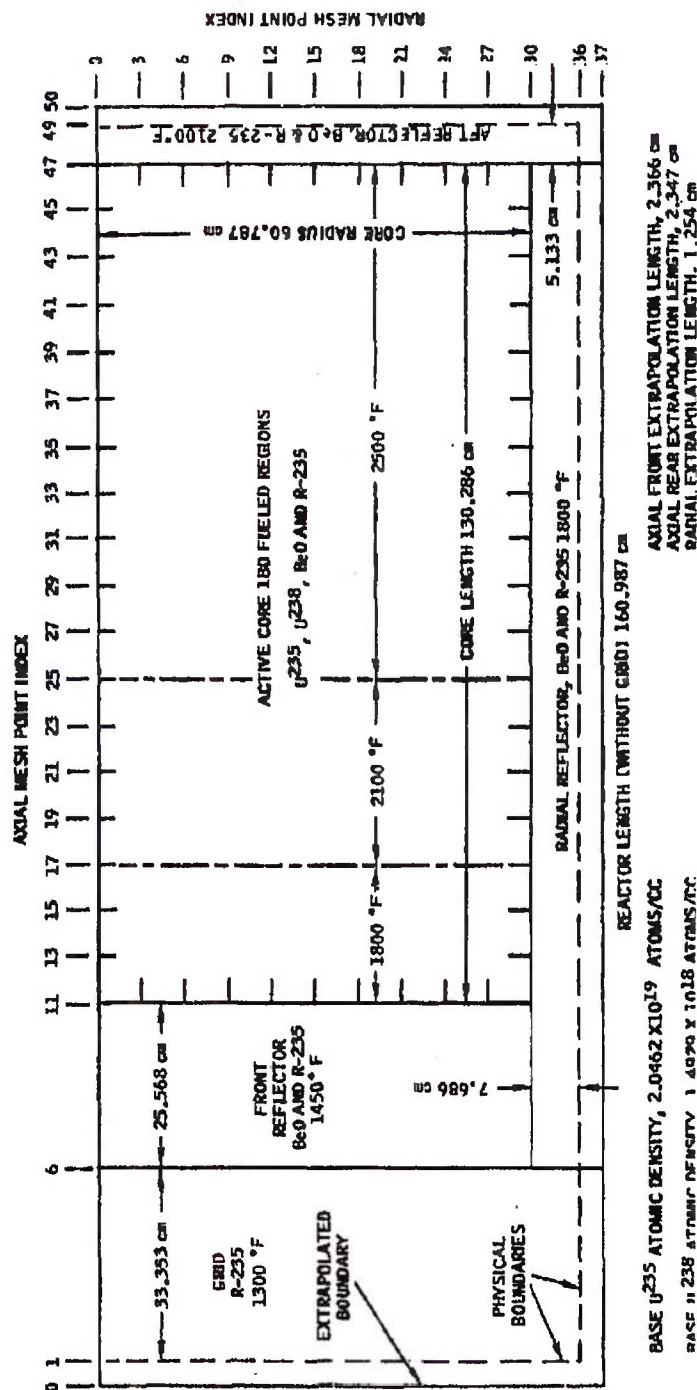
~~SECRET RESTRICTED DATA~~

*Marquardt*  
VAN NUYS, CALIFORNIA

5876

~~ATOMIC ENERGY ACT OF 1954~~

# GEOMETRY & PHYSICAL DATA FOR ANGIE NEUTRONICS MODEL (PROBLEM I.D. TOY 004)



~~SECRET RESTRICTED DATA~~

~~N22C29 ATOMIC ENERGY ACT OF 1954~~

-138-

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

FIGURE 74

SECRET RESTRICTED DATA


  
 VAN NUYS, CALIFORNIA

REPORT 5876

ATOMIC ENERGY ACT OF 1954

# POWER & FUEL DISTRIBUTION FOR FINAL ANGLE NEUTRONICS MODEL PROBLEM I.D. TOY 004

CORE AREA

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1.051 +5.1 1.491	1.034 +3.4 1.455	1.025 +2.5 1.331	1.014 +1.4 1.210	1.018 +1.8 1.206	1.029 +2.9 1.022	1.024 +2.4 1.000	1.027 +2.7 1.042	1.023 +2.3 1.075	1.005 +2.5 1.099	0.984 +2.8 1.106	0.930 +3.1 1.130	0.834 +3.1 1.143	0.733 +2.9 1.147	0.621 +3.1 1.143	0.499 +3.1 1.143	0.371 +4.8 1.116	0.239 +5.3 1.099
2	1.056 +5.6 1.500	1.045 +4.5 1.491	1.025 +2.5 1.371	1.021 +2.1 1.254	1.016 +1.6 1.143	1.020 +2.0 1.060	1.022 +2.2 1.033	1.027 +2.7 1.075	1.014 +2.4 1.116	1.004 +2.8 1.130	0.985 +3.1 1.143	0.911 +3.1 1.160	0.836 +3.1 1.181	0.735 +3.2 1.181	0.619 +3.2 1.181	0.497 +2.7 1.181	0.369 +4.2 1.160	0.240 +5.7 1.130
3	1.055 +5.5 1.641	1.036 +3.6 1.615	1.028 +2.8 1.470	1.015 +1.5 1.343	1.007 +0.7 1.222	1.023 +2.3 1.130	1.018 +1.8 1.099	1.021 +2.1 1.147	1.019 +2.2 1.181	0.995 +2.4 1.210	0.984 +2.8 1.222	0.910 +3.1 1.235	0.832 +3.1 1.254	0.731 +2.7 1.264	0.620 +3.0 1.254	0.493 +1.9 1.264	0.369 +4.2 1.235	0.239 +5.3 1.210
4	1.065 +6.5 1.804	1.031 +3.1 1.804	1.025 +2.5 1.641	1.043 +4.3 1.470	1.008 +0.8 1.360	1.023 +2.3 1.294	1.008 +0.8 1.222	1.016 +1.6 1.264	1.020 +2.0 1.303	0.982 +2.8 1.331	0.978 +3.1 1.343	0.904 +3.1 1.371	0.826 +3.1 1.395	0.725 +1.8 1.395	0.614 +2.0 1.395	0.489 +1.0 1.395	0.366 +3.4 1.366	0.237 +4.4 1.343
5	1.038 +3.8 2.113	1.035 +3.5 2.113	1.020 +2.0 1.923	1.013 +1.3 1.727	1.000 +0.0 1.565	1.009 +0.9 1.443	1.039 +3.9 1.395	1.032 +3.2 1.443	1.034 +3.7 1.491	1.030 +5.4 1.515	0.973 +5.4 1.540	0.900 +5.4 1.565	0.836 +5.4 1.593	0.735 +3.2 1.593	0.622 +3.3 1.593	0.499 +3.1 1.593	0.371 +4.8 1.565	0.240 +5.7 1.540
6	1.050 +5.0 2.529	1.027 +2.7 2.596	1.020 +2.0 2.364	1.021 +2.1 2.093	1.010 +1.0 1.876	1.017 +1.7 1.727	1.019 +1.9 1.669	1.038 +3.8 1.727	1.007 +1.7 1.777	1.020 +4.4 1.804	0.964 +2.6 1.841	0.891 +3.9 1.876	0.827 +2.2 1.905	0.726 +2.0 1.905	0.613 +1.8 1.905	0.497 +2.7 1.905	0.365 +3.1 1.876	0.240 +5.7 1.841
7	1.037 +3.7 3.193	1.030 +3.0 3.352	1.015 +1.5 3.031	1.010 +1.0 2.682	1.002 +0.2 2.381	0.990 -0.0 2.172	1.027 +2.7 2.093	1.040 +4.0 2.149	1.011 +1.1 2.210	0.975 +0.2 2.250	0.962 +2.3 2.281	0.889 +6.7 2.327	0.826 +2.1 2.364	0.724 +1.7 2.381	0.611 +1.5 2.381	0.491 +1.4 2.407	0.364 +2.8 2.364	0.237 +4.4 2.327
8	1.026 +2.6 4.215	1.023 +2.3 4.555	1.010 +1.0 4.094	0.998 -0.2 3.581	0.993 -0.7 3.130	0.996 -0.4 2.858	0.995 -0.5 2.728	1.004 +0.4 2.801	1.014 +1.7 2.858	0.976 -0.1 2.922	0.953 +1.4 2.981	0.879 -0.5 3.031	0.813 +0.5 3.096	0.712 +0.0 3.096	0.601 -0.2 3.130	0.490 +1.2 3.130	0.362 +2.3 3.096	0.237 +4.4 3.031
9	1.003 +0.3 5.772	1.008 +0.8 6.312	0.936 -16.4 5.772	0.981 -1.9 4.894	0.976 -2.4 4.249	0.980 -2.0 3.822	0.981 -1.9 3.648	0.987 -1.3 3.731	0.997 0.0 3.822	0.959 -1.8 3.890	0.936 -0.4 3.973	0.836 -2.3 4.055	0.800 -1.1 4.143	0.700 -1.7 4.143	0.590 -2.0 4.173	0.483 -0.2 4.215	0.355 0.3 4.173	0.235 +3.5 4.094
10	0.945 -5.5 7.584	0.945 -5.5 8.311	0.936 -6.4 7.331	0.925 -7.5 6.312	0.903 -9.7 5.442	0.931 -4.9 4.894	0.936 -4.4 4.659	0.940 -6.0 4.728	0.941 -5.6 4.812	0.992 -5.6 4.894	0.891 -5.2 5.007	0.822 -6.9 5.110	0.758 -5.3 5.226	0.663 -6.9 5.226	0.565 -6.1 5.276	0.458 -5.4 5.357	0.341 -3.7 5.357	0.221 -0.9 5.442

CORE FRONT - RADIAL REGIONS

CORE OUTER EDGE

NOTE:  
 RELATIVE POWER SHOWN ON UPPER PORTION OF REGION  
 MEAN PERCENTAGE DEVIATION FROM IDEAL POWER SHOWN  
 ON CENTER OF REGION

RELATIVE FUEL LOADING SHOWN ON LOWER PORTION OF REGION  
 IDEAL POWERS ARE SHOWN IN PARENTHESES AND ARE CONSTANT  
 FOR EACH RADIAL REGION  
 REGIONS ARE NOT TO SCALE

SECRET RESTRICTED DATA

N22C30 ATOMIC ENERGY ACT OF 1954

-140-

DECLASSIFIED IN FULL

Authority: EO 13526

Chief, Records &amp; Declass Div, WHS

Date:

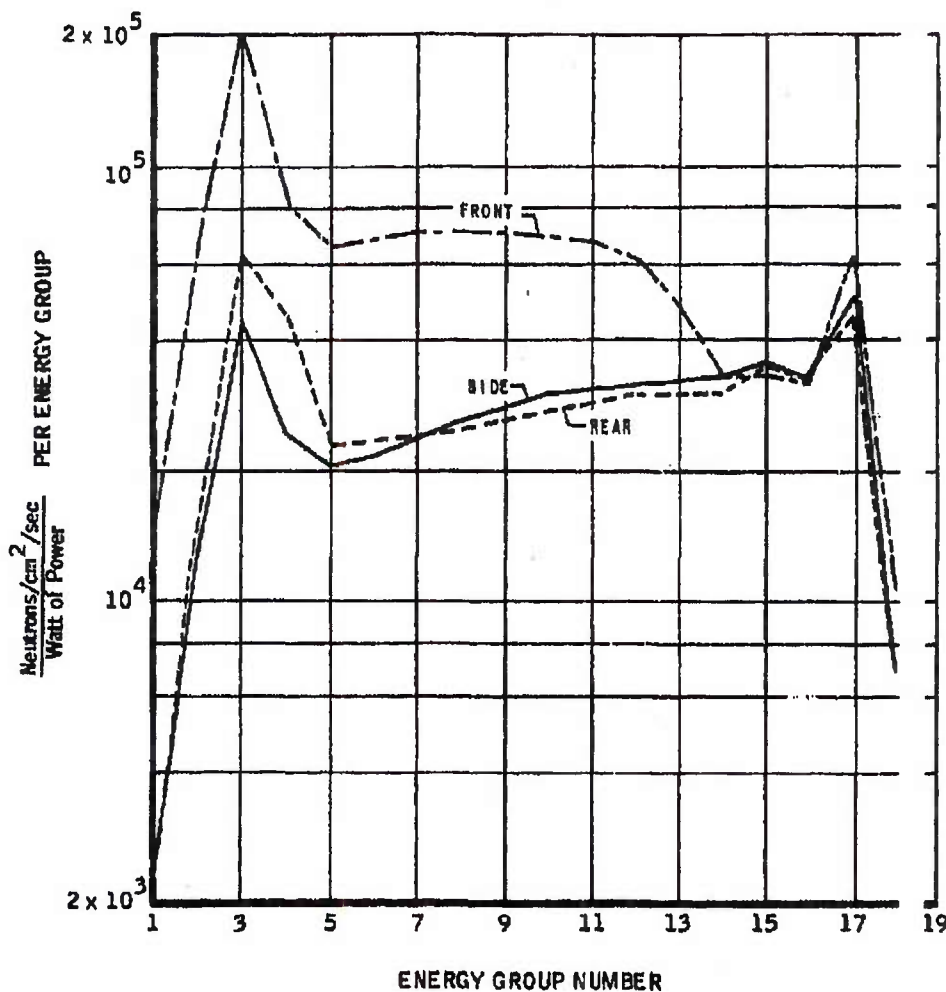
MAY 29 2015

FIGURE 15

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

MAXIMUM NEUTRON LEAKAGE CURRENT SPECTRA  
(PROBLEM I.D. TOY 004)



DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WIS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

N22C34 ~~ATOMIC ENERGY ACT OF 1954~~



~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

TABLE 11  
ANGIE ENERGY GROUP LIMITS

Energy Group	Energy Boundaries (ev)
1	$0 - 3.162 \times 10^{-2}$
2	$3.162 \times 10^{-2} - 1.0 \times 10^{-1}$
3	$1.0 \times 10^{-1} - 3.162 \times 10^{-1}$
4	$3.162 \times 10^{-1} - 1.0$
5	$1.0 - 3.162$
6	$3.162 - 1.0 \times 10^1$
7	$1.0 \times 10^1 - 3.162 \times 10^1$
8	$3.162 \times 10^1 - 1.0 \times 10^2$
9	$1.0 \times 10^2 - 3.162 \times 10^2$
10	$3.162 \times 10^2 - 1.0 \times 10^3$
11	$1.0 \times 10^3 - 3.162 \times 10^3$
12	$3.162 \times 10^3 - 1.0 \times 10^4$
13	$1.0 \times 10^4 - 3.162 \times 10^4$
14	$3.162 \times 10^4 - 1.0 \times 10^5$
15	$1.0 \times 10^5 - 3.162 \times 10^5$
16	$3.162 \times 10^5 - 1.0 \times 10^6$
17	$1.0 \times 10^6 - 3.162 \times 10^6$
18	$3.162 \times 10^6 - 1.0 \times 10^7$

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

~~SECRET RESTRICTED DATA~~

INT 5876

ATOMIC ENERGY ACT OF 1954

of the Model MA50-XCA system. The most significant change was the increased power generation in the forward regions of the core with a corresponding increase in fuel concentration. The neutronic feasibility of the isothermal wall depends on the maximum fuel concentration required in any particular region (a 10 percent (by weight) limit has been established by LRL as a reasonable maximum allowable fuel concentration).

The two-dimensional diffusion theory code, Angle, was used with 18 energy groups as in the basic Tory IIC model. Geometry and physical data for the model are identical to the data noted in Figure 74. The "ideal" radial power requirements for an isothermal wall system are shown in Figure 77. Radial power generation is assumed to be flat. Three 18-group Angle problems were required to match the desired profiles. The volumetrically weighted, average axial power profiles for each of the three cases are also shown in Figure 78.

The relative fuel distribution and relative power distribution for each of the 180 fueled regions of the reactor core are shown in Figure 78. The final fuel loading requirement imposed a maximum fuel concentration of 10.6 weight percent of uranium oxide in uranium oxide and beryllia. The resulting effective multiplication factor,  $k_{eff}$ , is 1.038 for a U-235 mass of 84.88 pounds. This value is compared with the 69.0 pounds required in the basic Tory IIC model for a  $k_{eff}$  of 1.033. It should be noted that both cases assume all R-235 rods in the reactor design. The maximum leakage flux profiles for the isothermal reactor are shown in Figure 79.

The isothermal wall version of the Tory IIC appears feasible from purely neutronic considerations although critical mass requirements have increased. Additional study of the configuration will be completed if thermal stress limitations are eased and if the enhanced performance is required in the system.

### 3.6.3 Reactor Sizing Studies

In addition to the isothermal wall system, the neutronic characteristics of three other possible reactor designs have been investigated during the year. Two designs were based on ceramic diameters of 59 inches and 64 inches. No changes in length or power distribution from the basic Tory IIC were incorporated in these two models. The third model used a ceramic diameter of 51.5 inches, with a 4.1-inch reduction in active core length and a 4-inch reduction in front reflector thickness to make the model 8.1 inches shorter than the basic Tory IIC design. The nuclear ramjet engine based on this reactor design is designated the Model MA50-XDA propulsion system.

MAC 402

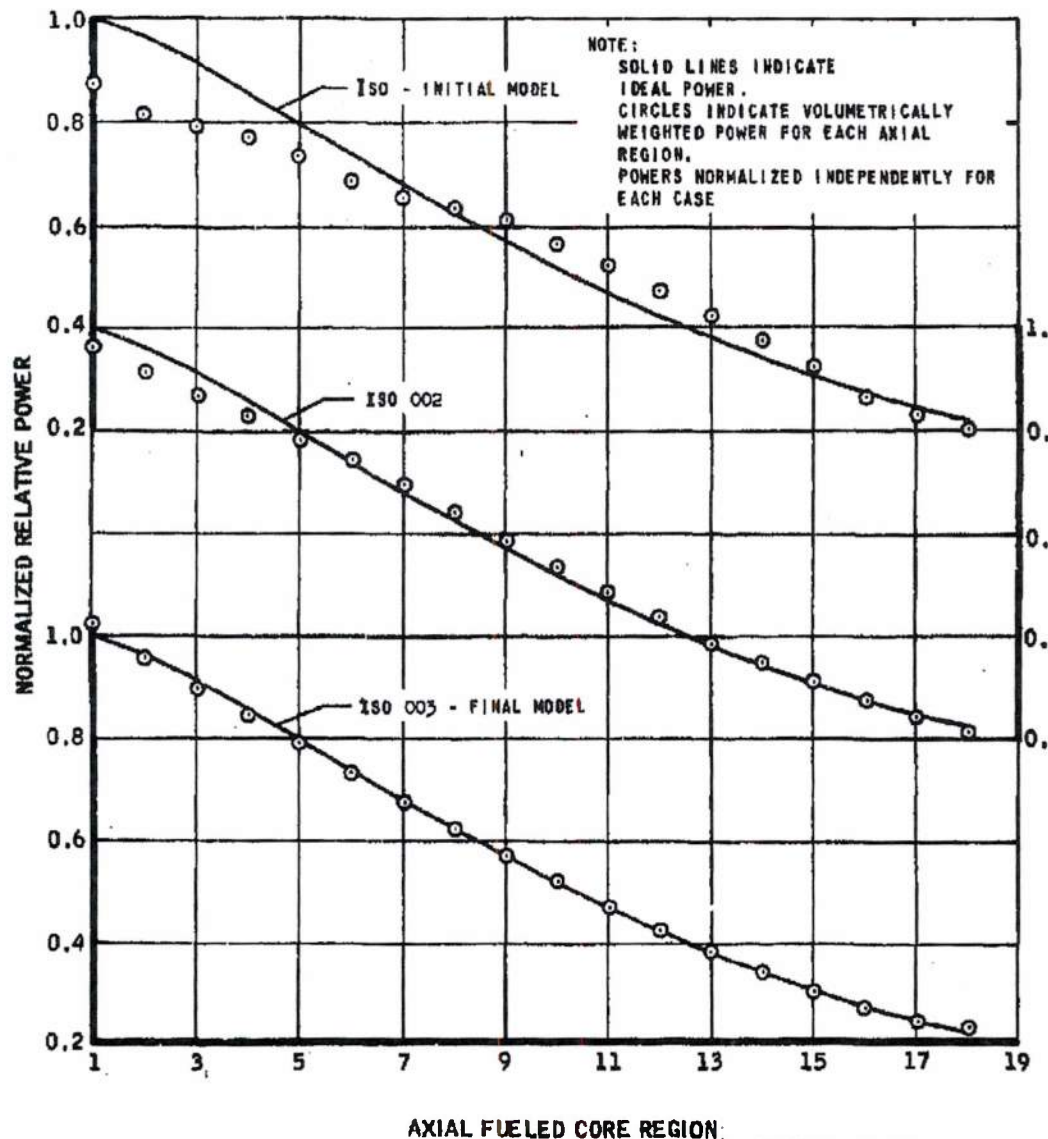
~~SECRET RESTRICTED DATA~~

ATOMIC ENERGY ACT OF 1954

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

AXIAL POWER CORRELATION FOR ANGE NEUTRONICS MODELS OF THE TORY IIC REACTOR  
ISOTHERMAL WALL - 2500° F



DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

N22C35 ~~ATOMIC ENERGY ACT OF 1954~~

SECRET RESTRICTED DATA

Marquardt  
VAN NUYS, CALIFORNIA

SEP

5876

ATOMIC ENERGY ACT OF 1954

POWER & FUEL DISTRIBUTION FOR FINAL ANGLE NEUTRONICS MODEL,  
ISOTHERMAL CORE (PROBLEM I.D. ISO 003)

CORE CENTER - AXIAL REGIONS																			CORE AFT																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1.050	959	902	841	784	720	650	609	562	504	495	411	372	334	303	275	234	237		1.050	959	902	841	784	720	650	609	562	504	495	411	372	334	303	275	234	237
	-5.0	-0.2	-1.1	-2.0	-1.6	-2.3	-4.3	-2.2	-1.4	-2.5	-1.9	-2.6	-2.6	-2.6	-2.3	-1.1	-5.6	+6.8		-5.0	-0.2	-1.1	-2.0	-1.6	-2.3	-4.3	-2.2	-1.4	-2.5	-1.9	-2.6	-2.6	-2.3	-1.1	-5.6	+6.8	
	3.512	3.561	2.998	2.461	1.997	1.663	1.453	1.266	1.152	1.069	1.015	1.000	1.012	1.069	1.170	1.365	1.772	2.371		3.512	3.561	2.998	2.461	1.997	1.663	1.453	1.266	1.152	1.069	1.015	1.000	1.012	1.069	1.170	1.365	1.772	2.371
2	1.047	956	897	843	781	721	650	612	559	508	459	411	372	336	302	272	247	234		1.047	956	897	843	781	721	650	612	559	508	459	411	372	336	302	272	247	234
	-4.7	-0.5	-1.6	-1.7	-2.0	-2.2	-4.3	-1.9	-1.9	-1.7	-1.9	-2.6	-2.6	-2.3	-2.6	-2.2	-0.4	+5.4		-4.7	-0.5	-1.6	-1.7	-2.0	-2.2	-4.3	-1.9	-1.9	-1.7	-2.6	-2.6	-2.3	-2.6	-2.2	-0.4	+5.4	
	3.659	3.720	3.114	2.549	2.062	1.723	1.486	1.304	1.192	1.099	1.042	1.024	1.039	1.086	1.192	1.405	1.772	2.461		3.659	3.720	3.114	2.549	2.062	1.723	1.486	1.304	1.192	1.099	1.042	1.024	1.039	1.086	1.192	1.405	1.772	2.461
3	1.050	965	896	850	784	720	668	610	557	503	459	410	372	335	296	272	245	237		1.050	965	896	850	784	720	668	610	557	503	459	410	372	335	296	272	245	237
	-5.0	+0.4	-1.8	-0.9	-1.6	-2.3	-1.6	-2.1	-1.7	-1.7	-1.9	-2.8	-2.6	-2.6	-4.3	-2.2	-1.2	+6.8		-5.0	+0.4	-1.8	-0.9	-1.6	-2.3	-1.6	-2.1	-1.7	-1.9	-2.8	-2.6	-4.3	-2.2	-1.2	+6.8		
	3.687	3.963	3.361	2.716	2.187	1.867	1.568	1.365	1.247	1.152	1.099	1.086	1.086	1.152	1.281	1.486	1.894	2.617		3.687	3.963	3.361	2.716	2.187	1.867	1.568	1.365	1.247	1.152	1.099	1.086	1.086	1.152	1.281	1.486	1.894	2.617
4	1.038	963	901	817	791	710	647	602	557	503	456	413	376	335	300	272	244	234		1.038	963	901	817	791	710	647	602	557	503	456	413	376	335	300	272	244	234
	-3.8	-0.2	-1.2	-4.8	-0.8	-5.7	-4.7	-3.4	-2.3	-2.7	-2.6	-2.1	-1.6	-2.6	-3.2	-2.2	-1.6	+5.4		-3.8	-0.2	-1.2	-4.8	-0.8	-5.7	-4.7	-3.4	-2.3	-2.7	-2.6	-2.1	-1.6	-2.6	-3.2	-2.2	-1.6	+5.4
	4.316	4.423	3.720	3.067	2.399	1.997	1.723	1.509	1.365	1.266	1.192	1.170	1.170	1.247	1.583	1.611	2.026	2.891		4.316	4.423	3.720	3.067	2.399	1.997	1.723	1.509	1.365	1.266	1.192	1.170	1.170	1.247	1.583	1.611	2.026	2.891
5	1.039	963	901	843	783	730	675	615	562	516	465	415	376	339	303	274	246	233		1.039	963	901	843	783	730	675	615	562	516	465	415	376	339	303	274	246	233
	-3.9	-0.2	-1.2	-1.7	-1.8	-0.9	-0.6	-1.3	-1.4	-0.2	-0.6	-1.7	-1.6	-1.5	-2.3	-1.4	-0.8	+5.0		-3.9	-0.2	-1.2	-1.7	-1.8	-0.9	-0.6	-1.3	-1.4	-0.2	-0.6	-1.7	-1.6	-1.5	-2.3	-1.4	-0.8	+5.0
	5.029	5.177	4.316	3.412	2.716	2.229	1.894	1.663	1.509	1.383	1.304	1.281	1.304	1.365	1.509	1.807	2.341	3.361		5.029	5.177	4.316	3.412	2.716	2.229	1.894	1.663	1.509	1.383	1.304	1.281	1.304	1.365	1.509	1.807	2.341	3.361
6	1.036	963	894	837	788	730	673	615	568	513	464	423	377	338	307	247	232	274		1.036	963	894	837	788	730	673	615	568	513	464	423	377	338	307	247	232	274
	+3.6	+0.2	-2.0	-2.4	-1.1	-0.9	-0.9	-1.3	-0.4	-0.8	-0.9	+0.2	-1.3	-1.7	-1.0	-0.4	+4.5	-1.4		+3.6	+0.2	-2.0	-2.4	-1.1	-0.9	-0.9	-1.3	-0.4	-0.8	-0.9	+0.2	-1.3	-1.7	-1.0	-0.4	+4.5	-1.4
	6.105	6.364	5.289	4.165	3.260	2.653	2.229	1.933	1.753	1.611	1.509	1.486	1.509	1.568	1.753	2.758	3.983	5.112		6.105	6.364	5.289	4.165	3.260	2.653	2.229	1.933	1.753	1.611	1.509	1.486	1.509	1.568	1.753	2.758	3.983	5.112
7	1.034	955	898	843	787	726	677	620	569	527	472	420	381	341	308	275	250	231		1.034	955	898	843	787	726	677	620	569	527	472	420	381	341	308	275	250	231
	+3.4	-0.6	-1.5	-1.7	-1.3	-1.5	-0.3	-0.5	-0.2	-1.2	+0.9	-0.5	-0.3	-0.9	-0.6	-1.1	+0.8	+4.1		+3.4	-0.6	-1.5	-1.7	-1.3	-1.5	-0.3	-0.5	-0.2	-1.2	+0.9	-0.5	-0.3	-0.9	-0.6	-1.1	+0.8	+4.1
	7.756	8.291	6.825	5.289	4.089	3.260	2.716	2.341	2.112	1.933	1.807	1.772	1.807	1.894	2.112	2.549	3.361	5.029		7.756	8.291	6.825	5.289	4.089	3.260	2.716	2.341	2.112	1.933	1.807	1.772	1.807	1.894	2.112	2.549	3.361	5.029
8	1.029	952	892	840	791	728	686	629	577	521	475	424	383	344	311	276	248	232		1.029	952	892	840	791	728	686	629	577	521	475	424	383	344	311	276	248	232
	+2.9	-0.4	-2.2	-2.1	-0.8	-1.2	+1.0	+1.0	+1.2	+0.8	+1.5	+0.5	+0.3	0.0	+0.3	-0.7	0.0	+4.5		+2.9	-0.4	-2.2	-2.1	-0.8	-1.2	+1.0	+1.0	+1.2	+0.8	+1.5	+0.5	+0.3	0.0	+0.3	-0.7	0.0	+4.5
	10.033	11.350	2.617	9.244	7.016	5.289	4.211	3.478	2.988	2.399	2.258	2.187	2.229	2.371	2.653	3.260	4.423	6.647		10.033	11.350	2.617	9.244	7.016	5.289	4.211	3.478	2.988	2.399	2.258	2.187	2.229	2.371	2.653	3.260	4.423	6.647
9	1.023	949	893	842	790	741	689	632	578	528	474	433	385	347	310	280	248	234		1.023	949	893	842	790	741	689	632	578	528	474	433	385	347	310	280	248	234
	-2.3	-1.2	-2.1	-1.9	-0.9	+0.5	+1.5	+1.4	+1.8	+1.4	+1.3	+2.6	+0.8	+0.9	0.0	+0.7	0.0	+5.4		-2.3	-1.2	-2.1	-1.9	-0.9	+0.5	+1.5	+1.4	+1.8	+1.4	+1.3	+2.6	+0.8	+0.9	0.0	+0.7	0.0	+5.4
	13.914	15.693	12.632	9.399	7.016	5.462	4.478	3.808	3.361	3.067	2.850	2.758	2.850	2.988	3.3	4.211	5.840	9.077		13.914	15.693	12.632	9.399	7.016	5.462	4.478	3.808	3.361	3.067	2.850	2.758	2.850	2.988	3.3	4.211	5.840	9.077
10	1.004	955	900	850	798	741	688	638	587	534	481	432	390	349	313	282	251	232		1.004	955	900	850	798	741	688	638	587	534	481	432	390	349	313	282	251	232
	+0.4	-0.6	-1.3	-0.9	+0.1	+1.3	+1.3	+2.4	+3.0	+3.3	+2.8	+2.4	+2.1	+1.5	+1.0	+1.4	+1.2	+4.5		+0.4	-0.6	-1.3	-0.9	+0.1	+1.3	+1.3	+2.4	+3.0	+3.3	+2.8	+2.4	+2.1	+1.5	+1.0	+1.4	+1.2	+4.5
	17.274	19.134	15.301	11.350	8.507	6.647	5.462	4.636	4.089	3.720	3.478	3.412	3.478	3.659	4.165	5.177	7.263	11.796		17.274	19.134	15.301	11.350	8.507	6.647	5.462	4.636	4.089	3.720	3.478	3.412	3.478	3.659	4.165	5.177	7.263	11.796

NOTE: RELATIVE POWER SHOWN ON UPPER PORTION OF REGION  
IDEAL POWERS ARE SHOWN IN PARENTHESES AND ARE  
CONSTANT FOR EACH RADIAL REGION

NOTE: RELATIVE DEVIATION OF POWER FROM IDEAL POWER  
SHOWN IN CENTER PORTION OF REGION  
RELATIVE FUEL LOADING SHOWN ON LOWER PORTION OF  
REGION  
REGIONS ARE NOT TO SCALE

SECRET RESTRICTED DATA

N22C31 ATOMIC ENERGY ACT OF 1954

-145-

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

FIGURE 78



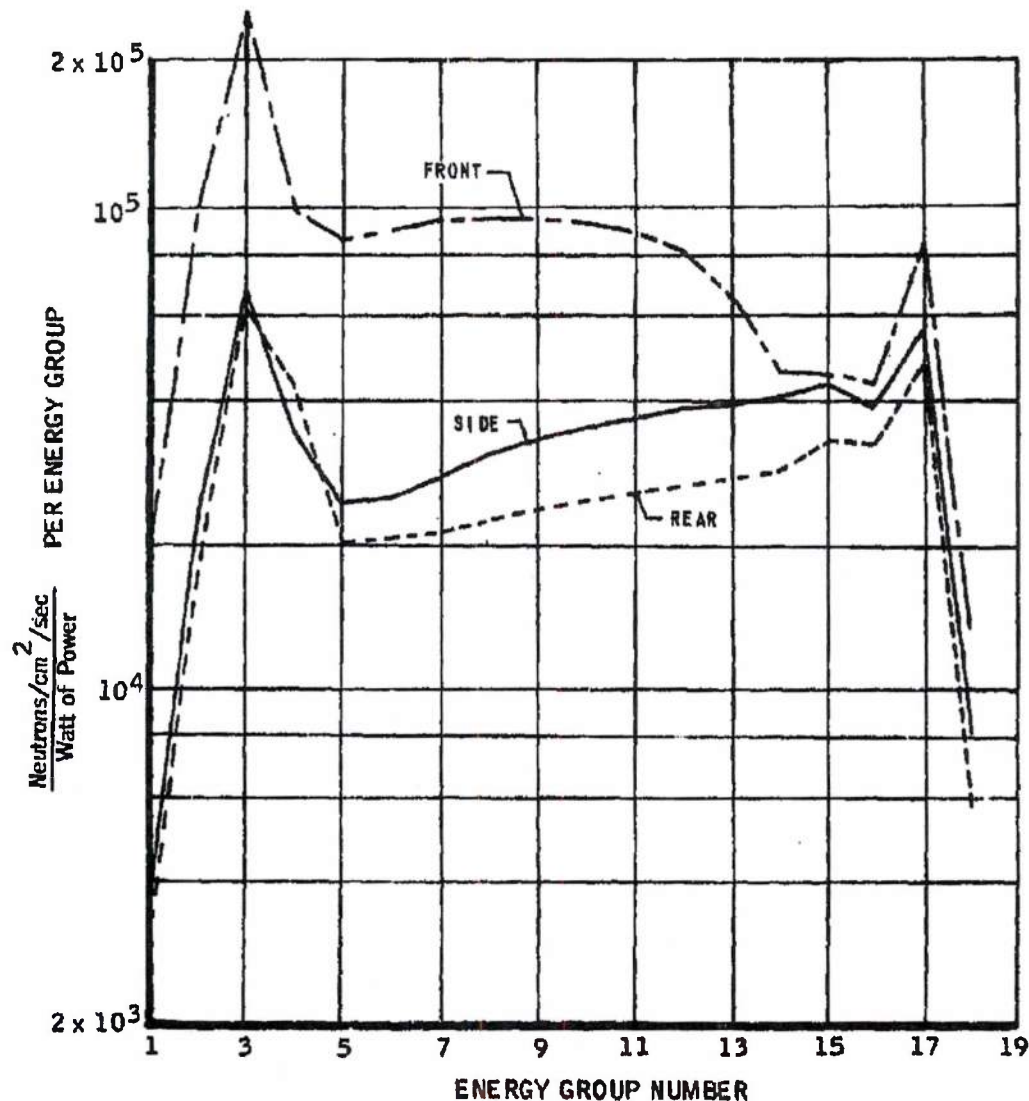
~~SECRET RESTRICTED DATA~~

*Arguand*  
VAN NUYS, CALIFORNIA

REPORT 5 '6

~~ATOMIC ENERGY ACT OF 1954~~

MAXIMUM NEUTRON LEAKAGE CURRENT SPECTRA  
(PROBLEM I. D. ISO 003)



DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~



ORT 5876

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

The geometry and physical data for the 59-inch diameter version of the Tory IIC reactor are shown in Figure 80. An initial fuel loading of 34.88 pounds was assumed giving a  $k_{eff}$  of 1.11. Critical mass iterations to reduce the  $k_{eff}$  were not completed due to computer time limitations. Three complete Angie problems were required to obtain proper convergence to the basic Tory IIC power distribution. The Angie-predicted power and fuel distributions are shown in Figure 81. Significant fuel reductions can be achieved with the design. Future iterations on fuel requirements will be completed if interest is expressed in the larger systems.

The geometry and physical data for the 64-inch diameter version of the Tory IIC reactor are shown in Figure 82 with the corresponding Angie-predicted power and fuel distributions noted in Figure 83. A  $k_{eff}$  of 1.12 is predicted for a fuel loading of 85 pounds. No iterations on fuel requirements for critical system were completed.

The design of particular interest was the shortened length, increased diameter version of Tory IIC designated as the reactor for the Model MA50-XDA propulsion system. The required core power distribution is identical to the basic Tory IIC without the aft 4.1 inches of core length. Satisfactory matching of the required power was accomplished with three Angie models. The final Angie neutronics model had a  $k_{eff}$  of 1.031 with a critical mass of 81.32 pounds. A maximum fuel concentration of 5.14 percent of uranium oxide in uranium oxide and beryllia was predicted in the calculation. This is well within allowable limits. The mean fission energy decreased slightly from 0.228 ev for the basic Tory IIC to 0.223 ev for the Model MA50-XDA system.

Geometrical data for the model are indicated in Figure 84 required fuel distributions in Figure 85, and corresponding maximum leakage currents for each energy group in Figure 86. The reactor appears feasible and may approach the flight type reactor for the nuclear ramjet system if the heat rates and heat exchanger surface areas are increased.

#### 3.6.4 Reactor Lifetime Studies and Time Effects

A limited analysis of the lifetime characteristics of Pluto type reactors has been performed to facilitate engine ground test planning. Additional extensive study will be required to assess adequately the time effects.

The much simplified initial analysis assessed the effects of fuel burnup, neutronic poison buildup, and loss of core material by erosion. A constant

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

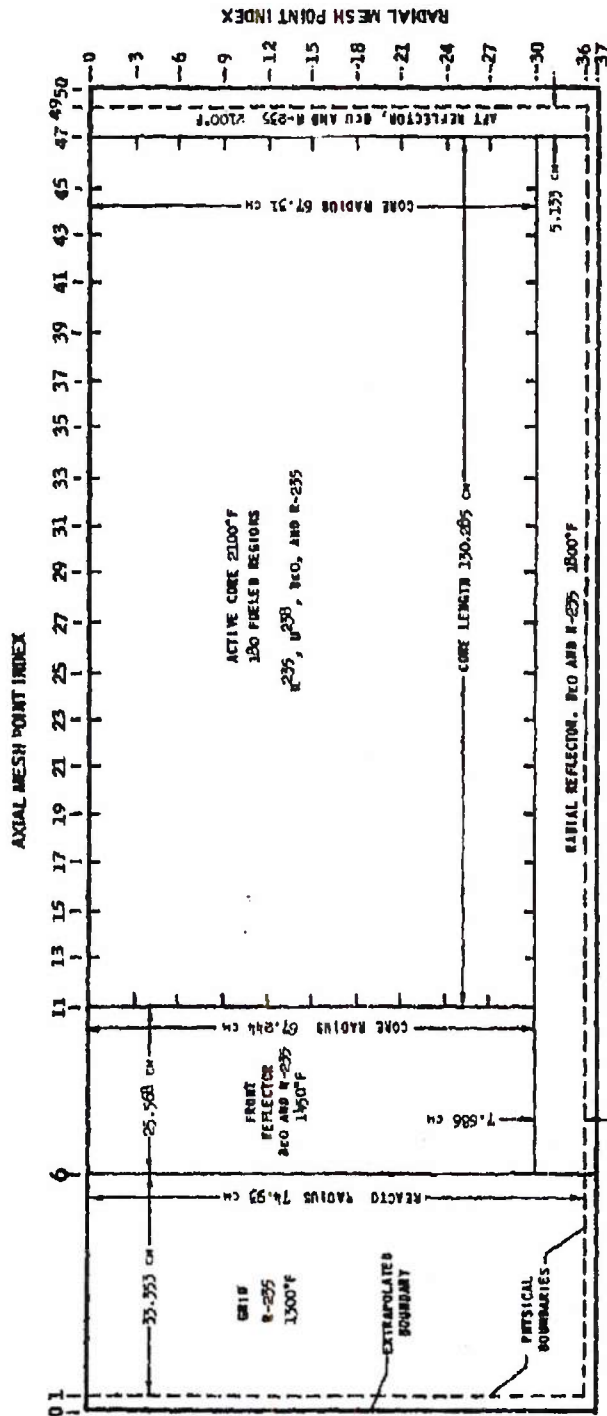
~~SECRET RESTRICTED DATA~~

*Marquardt*  
 VAN NUYS, CALIFORNIA

REPORT 587

~~ATOMIC ENERGY ACT OF 1954~~

GEOMETRY AND PHYSICAL DATA FOR ANGIE NEUTRONICS MODEL (PROBLEM I.D. BIG 002)



BASE  $^{235}\text{U}$  ATOMIC DENSITY,  $1.5835 \times 10^{19}$  atoms/cc

AXIAL FRONT EXTRAPOLATION LENGTH, 2.366 CM

BASE  $^{238}\text{U}$  ATOMIC DENSITY,  $1.1555 \times 10^{18}$  atoms/cc

AXIAL REAR EXTRAPOLATION LENGTH, 2.347 CM

RADIAL EXTRAPOLATION LENGTH, 1.254 CM

~~SECRET RESTRICTED DATA~~

N22C49 ~~ATOMIC ENERGY ACT OF 1954~~

~~SECRET RESTRICTED DATA~~

**THE Marquardt CORPORATION**  
**VAN NUYS, CALIFORNIA**

H Q. 5876

~~ATOMIC ENERGY ACT OF 1954~~

**CORE AFT**

POWER AND FUEL DISTRIBUTION FOR FINAL ANGLE NEUTRONICS MODEL (PROBLEM I.D. BIG 002)

[illegible]

**संक्षेप में**

**CORE FRONT - RADIAL REGIONS**

NOTE: RELATIVE POWER SHOWN IN UPPER PORTION OF REGION  
RELATIVE FUEL LOADING SHOWN IN LOWER PORTION OF REGION  
REGIONS ARE NOT TO SCALE  
IDEAL POWERS ARE SHOWN IN PARENTHESES AND ARE CONSTANT

~~SECRET RESTRICTED DATA~~

~~N22C50 ATOMIC ENERGY ACT OF 1954~~

- 149 -

FIGURE 81

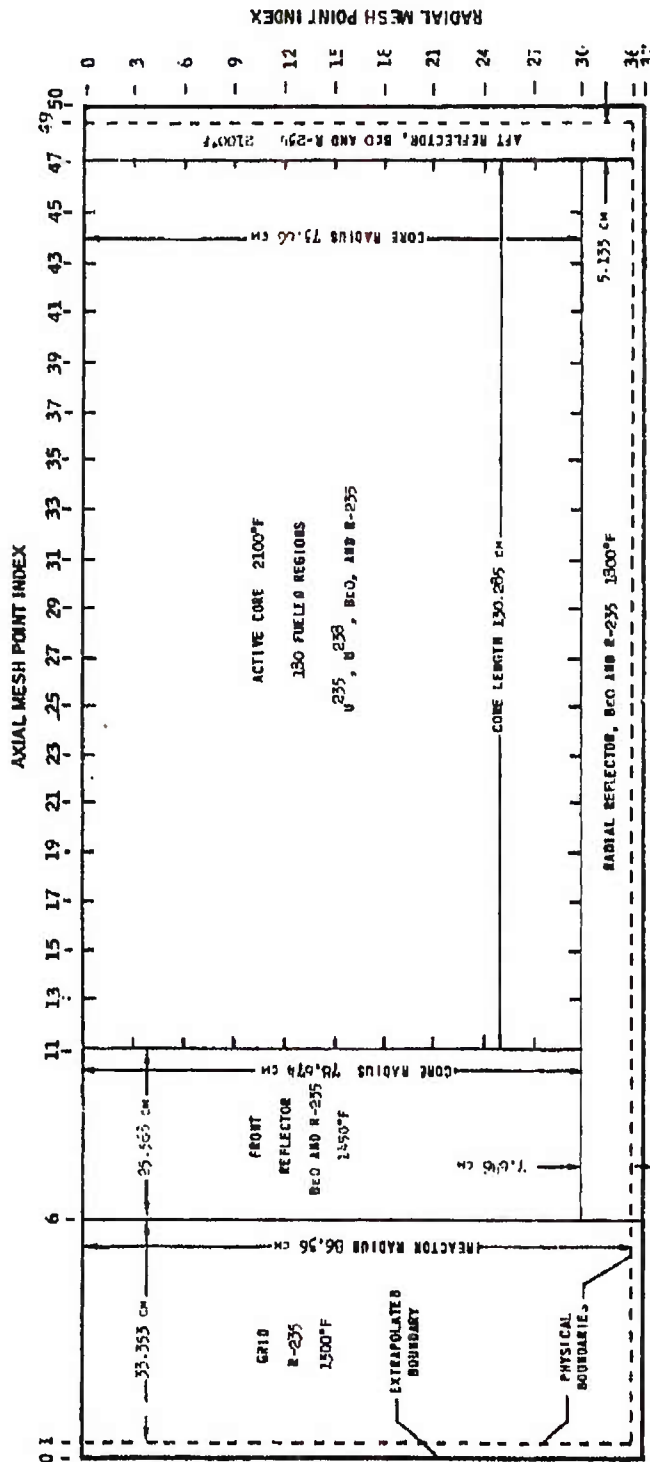


**SECRET RESTRICTED DATA**

REPORT 58 6

ATOMIC ENERGY ACT OF 1954

GEOMETRY AND PHYSICAL DATA FOR ANGIE NEUTRONICS MODEL (PROBLEM I.D. BST 005)



BASE <sup>235</sup>U ATOMIC DENSITY,  $1.4500 \times 10^{19}$  ATOMS/CC  
 BASE <sup>238</sup>U ATOMIC DENSITY,  $1.0506 \times 10^{20}$  ATOMS/CC  
 AXIAL FRONT EXTRAPOLATION LENGTH, 2.366 CM  
 AXIAL REAR EXTRAPOLATION LENGTH, 2.347 CM  
 RADIAL EXTRAPOLATION LENGTH, 1.254 CM

**SECRET RESTRICTED DATA**

SECRET RESTRICTED DATA  
ATOMIC ENERGY ACT OF 1954

**Marquardt**  
VAN NUYS, CALIFORNIA

PORT 5876

POWER AND FUEL DISTRIBUTION FOR FINAL ANGLE NEUTRONICS MODEL (PROBLEM I.D. BST 005)

	CORE CENTER - AXIAL REGIONS																		CORE AFT	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18		
1	1.281	1.003	0.974	0.993	0.994	1.003	1.008	0.991	0.990	0.973	0.951	0.932	0.922	0.912	0.902	0.892	0.882	0.872	0.862	0.852
2	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
3	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
4	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
5	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
6	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
7	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
8	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
9	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

CORE OUTER EDGE

NOTE: RELATIVE POWER SHOWN ON UPPER PORTION OF REGION  
RELATIVE FUEL LOADING SHOWN ON LOWER PORTION OF REGION  
REGIONS ARE NOT TO SCALE  
LOCAL POWERS ARE SHOWN IN PARENTHESES AND ARE CONSTANT FOR EACH RADIAL REGION

SECRET RESTRICTED DATA

N22C52 ATOMIC ENERGY ACT OF 1954

-151-

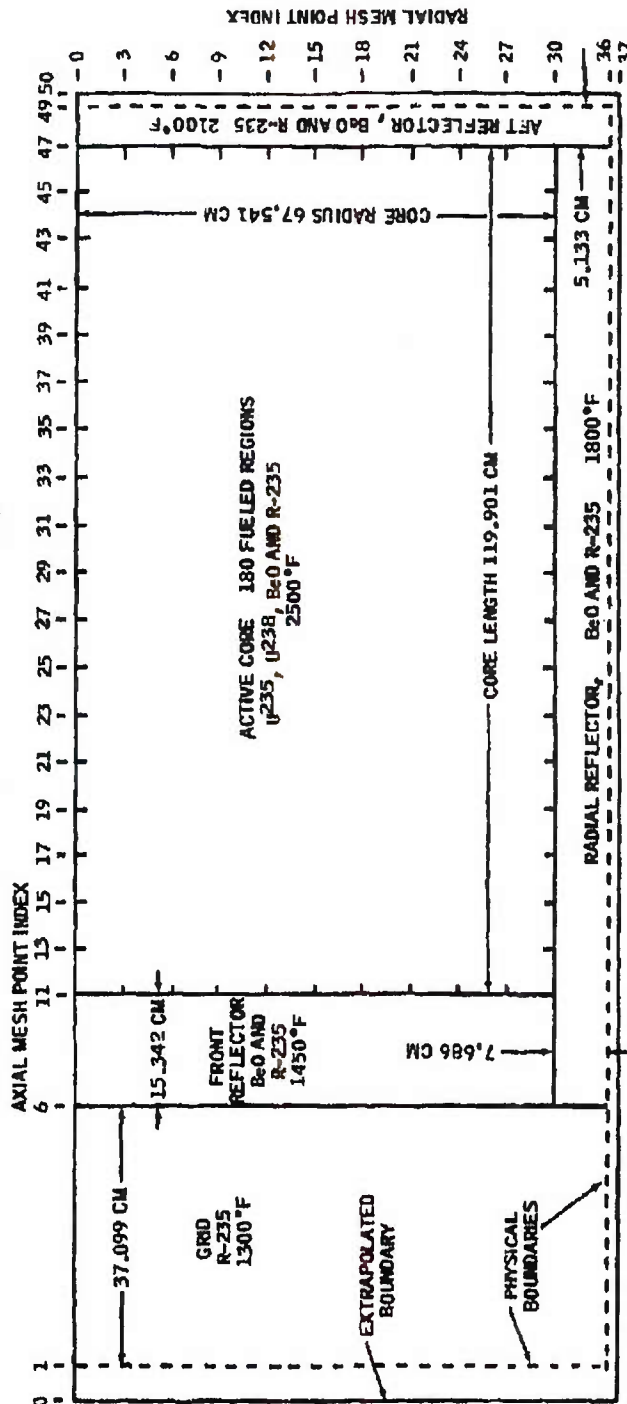
DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 20 2015

FIGURE 83

~~SECRET RESTRICTED DATA~~

ATOMIC ENERGY ACT OF 1954

**GEOMETRY AND PHYSICAL DATA FOR FINAL ANGLE NEUTRONICS MODEL  
MA50 XDA (PROBLEM I.D. FIN 003)**



AXIAL FRONT EXTRAPOLATION LENGTH, 5.065 CM  
AXIAL AFT EXTRAPOLATION LENGTH, 1.989 CM  
RADIAL EXTRAPOLATION LENGTH, 1.224 CM

BASE U-235 ATOMIC DENSITY, 1.64174 X 10<sup>19</sup> ATOMS/CC  
BASE U-238 ATOMIC DENSITY, 1.19783 X 10<sup>18</sup> ATOMS/CC  
REACTOR PHYSICAL LENGTH (WITHOUT GRID), 140.376 CM  
REACTOR PHYSICAL RADIUS, 75.227 CM

~~SECRET RESTRICTED DATA~~

N22C26 ATOMIC ENERGY ACT OF 1954

- 152 -

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

ORT 5876

POWER AND FUEL DISTRIBUTION FOR FINAL ANGLE NEUTRONICS MODEL  
MASO XDA PROBLEM ID. FN 003

CORE CENTER - AXIAL REGIONS

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	(1.000) 0.991 -0.56 1.968	(1.000) 0.996 -0.38 1.770	(1.000) 1.000 -0.05 1.519	(1.000) 0.995 -0.54 1.332	(1.000) 1.005 -0.55 1.183	(1.000) 1.005 -0.69 1.087	(1.000) 1.000 -0.04 1.034	(1.000) 1.002 -0.24 1.004	(1.000) 1.000 -0.35 1.000	(1.000) 0.985 -0.43 1.009	(1.000) 0.985 -0.43 1.009	(1.000) 0.912 -0.39 1.037	(1.000) 0.862 -0.39 1.087	(1.000) 0.785 -0.15 1.160	(1.000) 0.704 -0.04 1.248	(1.000) 0.619 -0.57 1.577	(1.000) 0.507 -0.57 1.571	(1.000) 0.398 -0.57 1.776
2	(1.000) 0.988 -1.22 2.032	(1.000) 0.993 -0.69 1.818	(1.000) 1.006 -0.56 1.571	(1.000) 0.993 -0.73 1.358	(1.000) 0.993 -0.73 1.219	(1.000) 0.997 -0.33 1.119	(1.000) 1.003 -0.32 1.057	(1.000) 1.005 -0.46 1.034	(1.000) 1.000 -0.56 1.027	(1.000) 0.980 -0.12 1.034	(1.000) 0.980 -0.12 1.034	(1.000) 0.913 -0.36 1.057	(1.000) 0.852 -0.36 1.130	(1.000) 0.791 -0.12 1.183	(1.000) 0.708 -0.04 1.271	(1.000) 0.613 -0.56 1.571	(1.000) 0.506 -0.56 1.506	(1.000) 0.398 -0.56 1.776
3	(1.000) 0.993 -0.70 2.140	(1.000) 0.998 -0.25 1.935	(1.000) 1.003 -0.28 1.655	(1.000) 0.994 -0.57 1.457	(1.000) 1.002 -0.20 1.290	(1.000) 1.003 -0.33 1.183	(1.000) 1.003 -0.57 1.057	(1.000) 1.003 -0.29 1.034	(1.000) 1.003 -0.16 1.034	(1.000) 0.978 -0.31 1.100	(1.000) 0.978 -0.31 1.100	(1.000) 0.917 -0.31 1.044	(1.000) 0.857 -0.31 1.192	(1.000) 0.785 -0.18 1.271	(1.000) 0.707 -0.04 1.358	(1.000) 0.620 -0.71 1.501	(1.000) 0.507 -0.42 1.704	(1.000) 0.397 -0.42 1.937
4	(1.000) 0.991 -0.37 2.535	(1.000) 0.991 -0.65 2.140	(1.000) 0.999 -0.11 1.842	(1.000) 0.993 -0.70 1.571	(1.000) 1.002 -0.19 1.414	(1.000) 0.998 -0.49 1.290	(1.000) 1.003 -0.29 1.219	(1.000) 1.003 -0.24 1.192	(1.000) 1.006 -0.16 1.183	(1.000) 0.988 -0.72 1.192	(1.000) 0.988 -0.72 1.192	(1.000) 0.916 -0.39 1.219	(1.000) 0.855 -0.39 1.248	(1.000) 0.785 -0.07 1.377	(1.000) 0.705 -0.18 1.482	(1.000) 0.621 -0.81 1.655	(1.000) 0.510 -0.20 1.885	(1.000) 0.389 -0.20 2.035
5	(1.000) 0.986 -0.68 2.693	(1.000) 0.991 -0.93 2.456	(1.000) 0.989 -1.11 2.104	(1.000) 1.001 -0.07 1.818	(1.000) 0.996 -0.44 1.606	(1.000) 0.998 -0.28 1.456	(1.000) 1.004 -0.38 1.377	(1.000) 1.006 -0.58 1.332	(1.000) 1.006 -0.91 1.332	(1.000) 0.981 -0.85 1.358	(1.000) 0.981 -0.85 1.358	(1.000) 0.918 -0.54 1.377	(1.000) 0.859 -0.54 1.482	(1.000) 0.786 -0.20 1.571	(1.000) 0.704 -0.01 1.704	(1.000) 0.613 -0.49 1.885	(1.000) 0.506 -0.57 2.156	(1.000) 0.389 -0.57 2.560
6	(1.000) 0.986 -1.35 3.200	(1.000) 0.993 -0.74 2.968	(1.000) 0.999 -0.10 2.527	(1.000) 0.992 -0.76 2.156	(1.000) 0.994 -0.62 1.904	(1.000) 0.998 -0.08 1.731	(1.000) 1.004 -0.38 1.616	(1.000) 1.001 -0.51 1.571	(1.000) 1.001 -0.51 1.571	(1.000) 0.987 -0.64 1.616	(1.000) 0.987 -0.64 1.616	(1.000) 0.908 -0.64 1.616	(1.000) 0.858 -0.64 1.731	(1.000) 0.793 -0.19 1.842	(1.000) 0.710 -0.04 2.001	(1.000) 0.619 -0.41 2.252	(1.000) 0.509 -0.05 2.560	(1.000) 0.395 -0.05 3.049
7	(1.000) 0.986 -2.26 4.022	(1.000) 0.992 -0.85 3.744	(1.000) 0.992 -1.42 3.200	(1.000) 0.989 -1.14 2.593	(1.000) 0.991 -0.93 2.355	(1.000) 0.998 -0.18 2.140	(1.000) 0.998 -0.22 2.001	(1.000) 1.003 -0.35 1.935	(1.000) 1.005 -0.91 1.904	(1.000) 0.979 -0.16 1.935	(1.000) 0.979 -0.16 1.935	(1.000) 0.919 -0.85 1.968	(1.000) 0.855 -0.85 2.032	(1.000) 0.791 -0.90 2.294	(1.000) 0.713 -0.26 2.486	(1.000) 0.618 -0.35 2.830	(1.000) 0.508 -0.16 3.251	(1.000) 0.395 -0.16 3.807
8	(1.000) 0.977 -3.315	(1.000) 0.988 -1.23 4.997	(1.000) 0.986 -1.42 4.232	(1.000) 0.994 -0.85 3.555	(1.000) 0.991 -0.94 3.049	(1.000) 0.998 -0.22 2.753	(1.000) 0.998 -0.08 2.560	(1.000) 1.004 -0.40 2.456	(1.000) 1.006 -1.01 2.456	(1.000) 0.980 -0.10 2.486	(1.000) 0.980 -0.10 2.486	(1.000) 0.915 -0.85 2.527	(1.000) 0.856 -0.85 2.753	(1.000) 0.791 -0.93 2.968	(1.000) 0.706 -0.22 3.283	(1.000) 0.613 -0.39 3.744	(1.000) 0.512 -0.16 4.345	(1.000) 0.395 -0.16 5.181
9	(1.000) 0.982 -1.30 7.242	(1.000) 0.984 -1.59 6.934	(1.000) 0.985 -1.53 5.776	(1.000) 0.983 -1.70 4.783	(1.000) 0.994 -0.63 4.072	(1.000) 0.998 -0.22 3.624	(1.000) 1.001 -0.08 3.353	(1.000) 1.003 -0.27 3.251	(1.000) 1.005 -0.93 3.280	(1.000) 0.990 -0.44 3.251	(1.000) 0.990 -0.44 3.251	(1.000) 0.913 -0.52 3.476	(1.000) 0.856 -0.52 3.674	(1.000) 0.793 -0.19 3.966	(1.000) 0.707 -0.04 4.409	(1.000) 0.622 -0.35 5.078	(1.000) 0.509 -0.06 5.989	(1.000) 0.394 -0.06 7.260
10	(1.000) 0.982 -1.83 9.254	(1.000) 0.984 -1.57 8.770	(1.000) 0.984 -1.55 7.242	(1.000) 0.989 -1.13 5.989	(1.000) 0.982 -0.80 5.078	(1.000) 0.997 -0.32 4.527	(1.000) 1.003 -0.28 4.187	(1.000) 1.009 -0.85 4.028	(1.000) 0.998 -0.16 4.028	(1.000) 0.984 -0.29 4.072	(1.000) 0.984 -0.29 4.072	(1.000) 0.913 -0.50 4.345	(1.000) 0.861 -0.50 4.585	(1.000) 0.790 -0.81 4.997	(1.000) 0.708 -0.64 5.524	(1.000) 0.619 -0.50 6.394	(1.000) 0.510 -0.27 7.650	(1.000) 0.395 -0.27 9.621

CORE FRONT - RADIAL REGIONS

CORE OUTER EDGE

NOTE:  
IDEAL POWERS ARE SHOWN IN PARENTHESES AND ARE  
CONSTANT FOR EACH RADIAL REGION.  
RELATIVE FUEL LOADING SHOWN ON LOWER PORTION OF REGION.  
REGIONS ARE NOT TO SCALE.

NOTE:  
IDEAL POWERS ARE SHOWN IN PARENTHESES AND ARE  
CONSTANT FOR EACH RADIAL REGION.  
RELATIVE FUEL LOADING SHOWN ON LOWER PORTION OF REGION.  
REGIONS ARE NOT TO SCALE.

~~SECRET RESTRICTED DATA~~

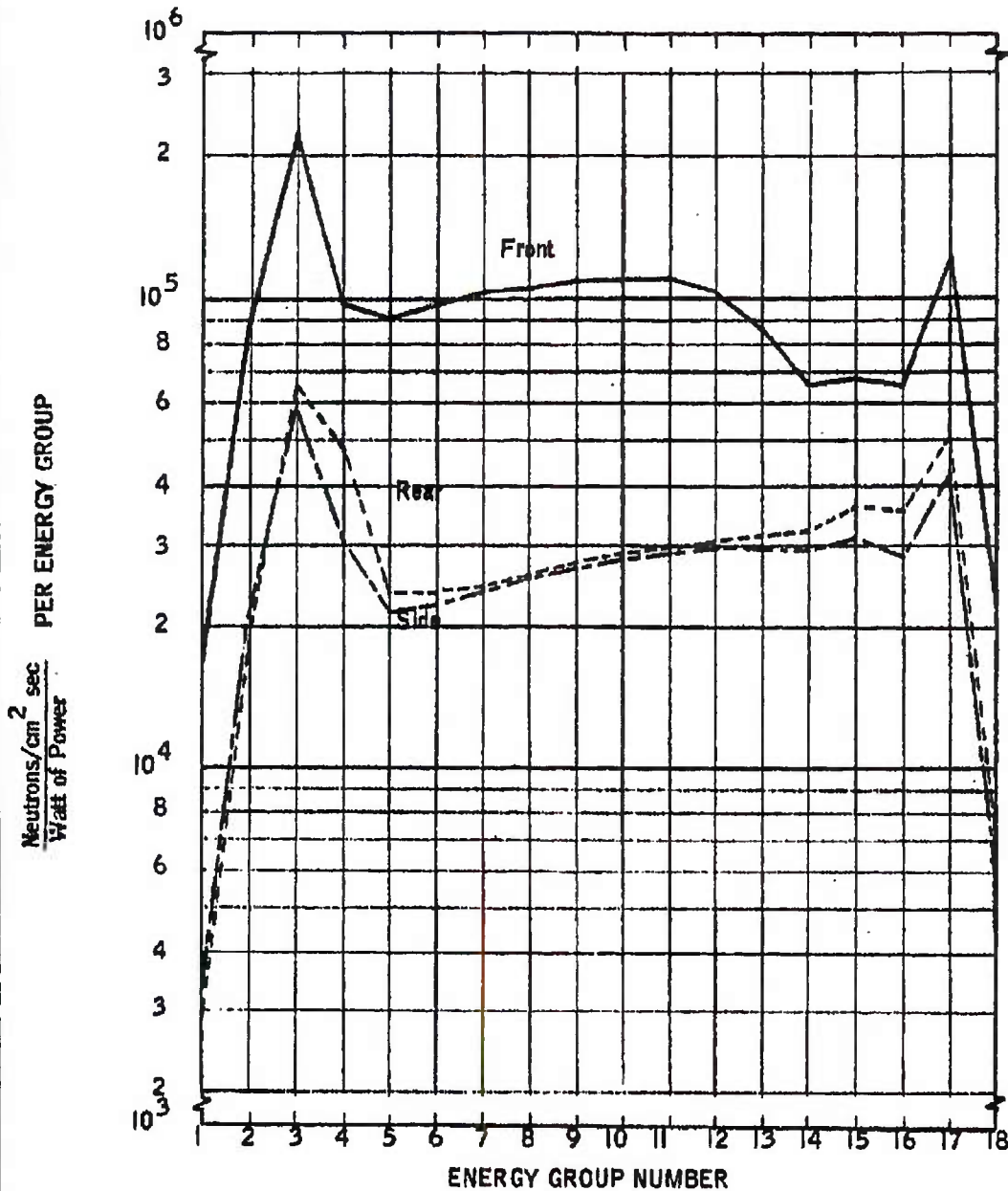
N22C27 ~~ATOMIC ENERGY ACT OF 1954~~



~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

MAXIMUM NEUTRON LEAKAGE FLUX SPECTRA  
PROBLEM I. D. FIN 003



~~SECRET RESTRICTED DATA~~

N22C28 ~~ATOMIC ENERGY ACT OF 1954~~



~~SECRET RESTRICTED DATA~~

OST 5876

~~ATOMIC ENERGY ACT OF 1954~~

erosion rate of 0.2 percent of core material per hour of operating time was assumed for the period of operation. Such a rate would result in a change in  $k_{eff}$  of 0.005 per hour. The results of a one-group homogeneous burnup calculation were compared with calculations of the Marquardt two-dimensional multigroup burnup code Firedragon over a typical Pluto flight history. The simplified model was found to give conservative answers and was accepted for the preliminary analysis noted here. The required initial multiplication factor at operating temperature is shown in Figure 87 as a function of reactor lifetime for two total power conditions.

The effects of operating time on the system can be divided into two parts. First, the effect of the accumulation of fission products, which include xenon-135 and samarium-149 as well as those that emit gamma rays with energy above the  $Be^9(\gamma, n)Be^8$  threshold. Second, the effects of control rod motion on the power distribution.

The poison effect in  $k_{eff}$  is readily obtained by solving the conventional fission product production equations for each region of the reactor. The effect of the  $Be^9(\gamma, n)Be^8$  reaction on  $k_{eff}$  can be estimated in terms of  $k_{eff}$  and the effective delayed neutron fraction.

The changes in  $k_{eff}$  and in power distribution resulting from control rod motion are more difficult to calculate. Knowing the reactivity compensation required for poison buildup, the corresponding control rod positions can be computed with the Angie program using the method of Wachspress (Reference 18) to represent a thin, cylindrical poison ring.

A method is being developed for the synthesis of three-dimensional power shapes in the reactor with the control rods inserted. This synthesis is necessitated by the fact that the physical arrangement of the control rods is inconsistent with the mathematical model used to calculate control rod worth.

### 3.6.5 Neutronics Methods Development

Calculation methods development has been required to allow a faster and more reliable evaluation of Pluto type reactors. Additional work in this area is anticipated.

The IBM-704 program Angelita was developed to prepare input for the Angie program. Angelita uses flux-weighted average fission microscopic cross sections as a function of the density of the fissionable material to determine the

MAC 103

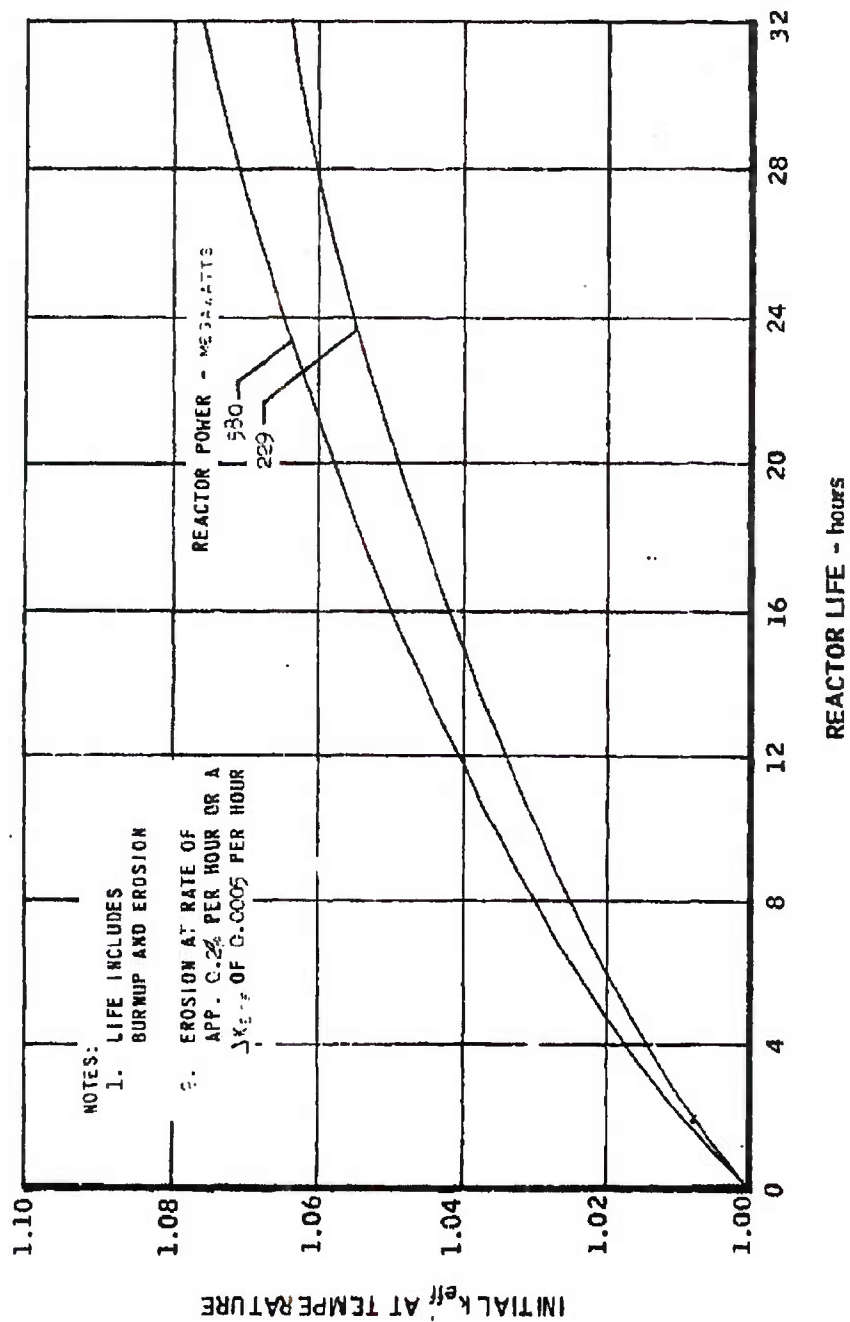
~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

INITIAL MULTIPLICATION FACTOR AS A FUNCTION OF REACTOR LIFE



~~SECRET RESTRICTED DATA~~

~~N22C43 ATOMIC ENERGY ACT OF 1954~~



~~SECRET RESTRICTED DATA~~

5876

~~ATOMIC ENERGY ACT OF 1954~~

new fuel distribution from the previous power profiles and fuel distributions. The program also punches cards in Angle input format to give the relative distributions of all materials in the reactor.

The IBM-704 program Flexita reads the relative neutron fluxes from Angle output tapes, averages the mesh point fluxes for each region, and obtains the volume weighted average flux over the entire core for each energy group. The program also averages the powers for each region, normalizes them, and renormalizes them to any desired position.

The IBM-704 FORTRAN code Pronto was developed for the preparation of cross section input to the reactor code PDO. The program calculates macroscopic diffusion, absorption, removal, and fission cross sections for each group and each region from microscopic cross sections and atomic densities.

A study of the validity of diffusion theory for analysis of P1 type reactors has been initiated. In using diffusion codes for reactor computations, it is necessary to represent the reactor by many regions of sufficient size to make diffusion theory applicable. The requirement of small regions for adequate representation of spatial variation is incompatible with the requirement of large regions demanded by diffusion theory. It is conceivable that in some cases there is no "mesh size" that satisfies both requirements adequately. Initial investigations of the question will be made using a one-dimensional, one-velocity transport equation. Studies will be extended to verify the validity of power distributions derived from application of diffusion theory.

### 3.7 Radiation Analysis and Shielding

The radiation analysis and shielding effort is concerned with specifying the Pluto in-flight radiation environment, description of radiation environment and hazards during launch, delineation of shielding and nuclear heating problems, and integration of overall system shielding requirements.

Work performed during 1961 has resulted in the specification of the Pluto radiation environment comprising dose rate information, neutron and gamma spectrum data, and reactor leakage flux. Nuclear heating studies of many engine components have been completed, but additional studies will be required during the 1962 contract period. System shielding requirements, not studied in great detail during the contract year, will be pursued further during 1962.

DECLASSIFIED IN FULL

Authority: EO 13526

Chief, Records & Declass Div, WHS

Date: MAY 29 2015

MAC AGO

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~



DECLASSIFIED IN FULL

Authority: EO 13526

Chief, Records & Declass Div, WHS

Date: MAY 29 2015



~~SECRET RESTRICTED DATA~~

REPORT 58

ATOMIC ENERGY ACT OF 1954

### 3.7.1 Computation of Radiation Levels for the Tory IIC Reactor

Radiation levels for the Tory IIC reactor have been calculated and presented in the form of neutron and gamma isodose curves and doses for the reactor in Figures 88 and 89. The radiation levels are consistent with the information published by LRL in the Tory IIC Data Book. These results will be reviewed and updated as the Tory IIC reactor design becomes more firmly established.

The General Electric Shielding Program 04-2 was used to obtain both the neutron and gamma dose rates at various positions outside the reactor.

The radial power distribution within the core was taken to be flat, while the axial power distribution was obtained by fitting curves to the data in Reference 19. The core was longitudinally divided into four regions with each region being represented by an appropriate power distribution function. The functions used to fit the data were as follows:

<u>Function</u>	<u>Range*, (cm)</u>
$P(Z) = 1$	5 to 64.4
$P(Z) = \cos 0.027(Z-5)$	-5 to 5
$P(Z) = \cos 0.0183(Z-9.8)$	-5 to -35
$P(Z) = \cos 0.0202(Z-5.625)$	-35 to -64.4

### 3.7.2 Gamma Spectra for Tory IIC

The General Dynamic Shielding Program D-53 was used for determining the energy spectrum of the gamma radiation from the Tory IIC reactor. The code employs moments method data (Reference 20) to specify the transfer of photons between energy levels. The reactor core is divided into 254 volume elements, and the power within each volume element is calculated. The code assumes that the power comes from a point source located in the center of each volume element.

The geometric configuration and the composition of the reactor must be specified in order to calculate the number of mean free paths,  $\mu r$ , of material encountered in traversing the distance from each source point to the detector point in question. Use of the value of  $\mu r$  for different materials in the equation for  $I_0$ ,  $(E, E_0, \mu r)$  effectively assumes that the scattering effect of the material is equivalent to that of an equal number of mean free paths of beryllia.

\*Referenced to core geometrical center

~~SECRET RESTRICTED DATA~~

ATOMIC ENERGY ACT OF 1954

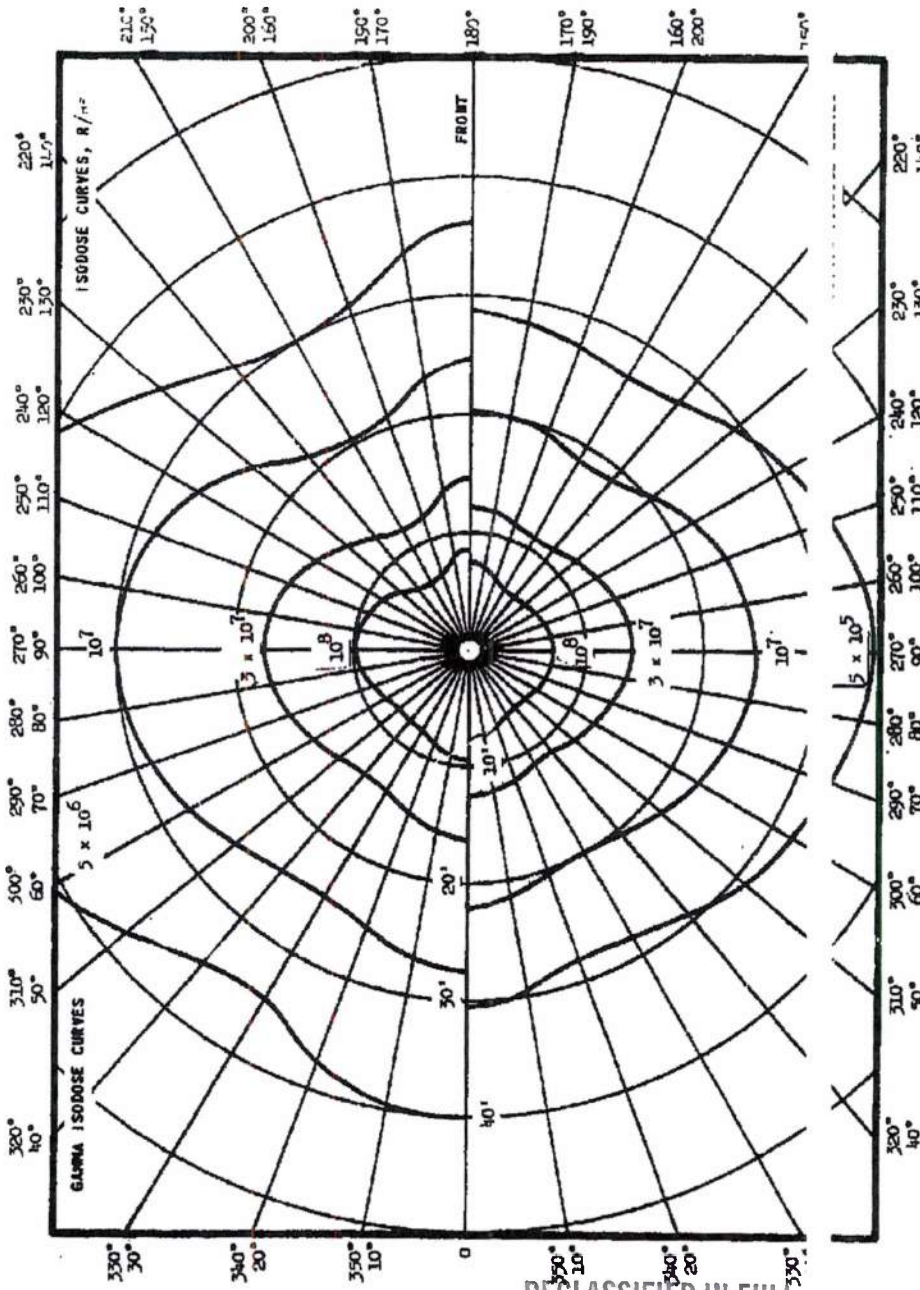
~~SECRET RESTRICTED DATA~~

*Harquardt*  
VAN NUYS, CALIFORNIA

MT 5876

~~ATOMIC ENERGY ACT OF 1954~~

GAMMA AND NEUTRON ISODOSE CURVES



DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

MAC AGS

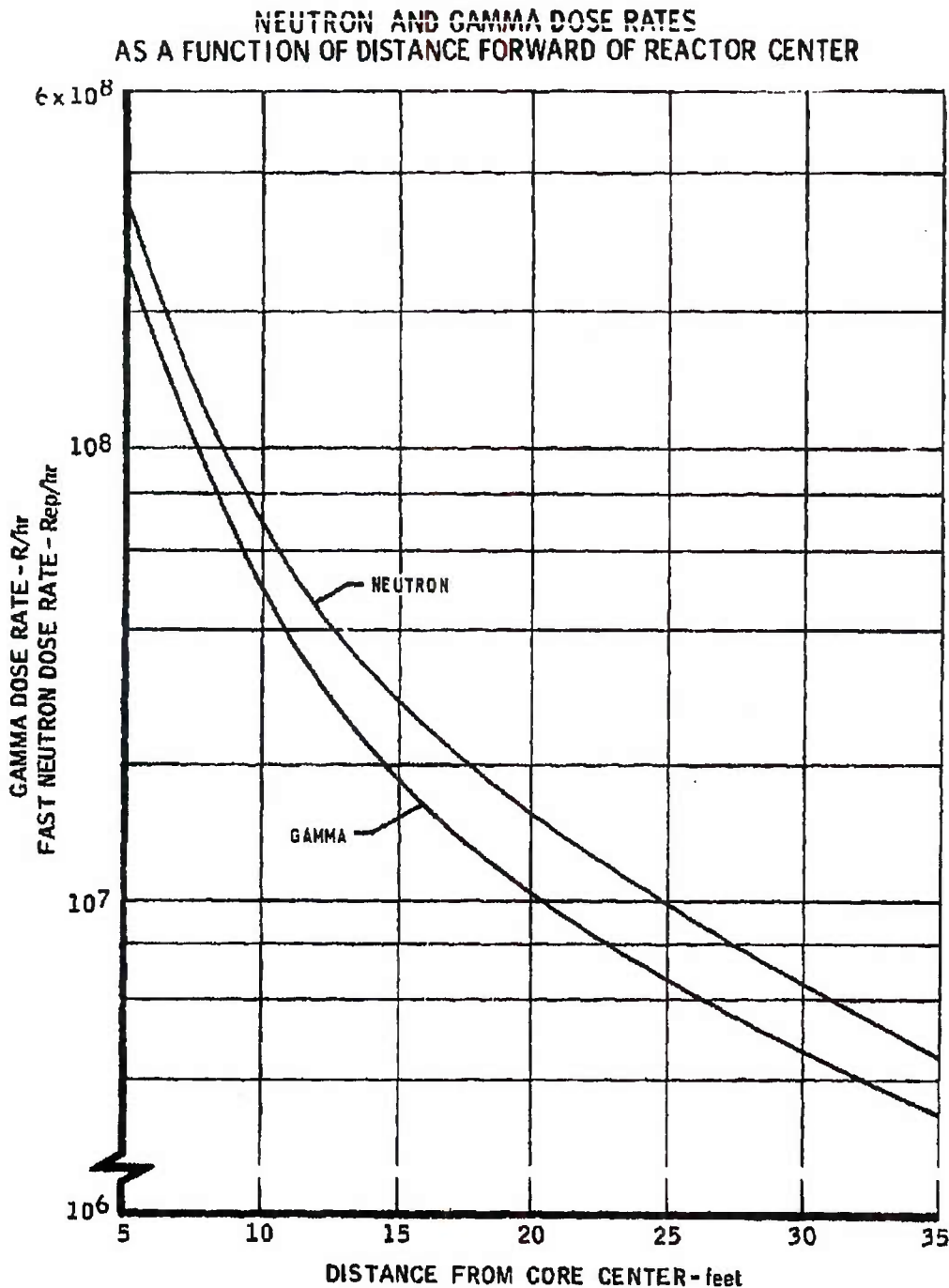
~~SECRET RESTRICTED DATA~~

N22A8 ~~ATOMIC ENERGY ACT OF 1954~~ -T59-

FIGURE 88

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~



~~SECRET RESTRICTED DATA~~

N22A27 ~~ATOMIC ENERGY ACT OF 1954~~

-160-

FIGURE 89





~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

The output of the Program D-53 gives flux values for seven energy levels as well as the total dose. The total dose is calculated by (1) utilizing flux-to-dose conversion factors for the seven energy levels and (2) numerically integrating over the energy interval.

The Program 04-2 was run for each of the receiver points in order to obtain total doses that could be compared with the Program D-53 doses. The results are compared in Table 12.

### 3.7.3 Neutron Spectra for Tory IIC

The Program 04-2 was used to calculate the neutron spectra of the Tory IIC reactor utilizing moments method data for beryllia. The data furnish a differential number flux per Mev,  $N_0(r, E)$ , as a function of energy and penetration distance for a unit point isotropic fission source in beryllia. The neutron flux per Mev,  $\phi(r, E)$ , outside the reactor can be calculated by performing the three Program 04-2 integrations over the Albert-Welton kernel (see Reference 21 for appropriate values of Albert-Welton constants).

The neutron flux per Mev,  $\phi(r, E)$ , was calculated for six energy levels:  $E = 0.33, 1.096, 2.44, 3.64, 5.43$ , and  $8.10$  Mev. The neutron spectra were established at eight receiver points, and the results are tabulated in Table 13. The results are for a power level of 1 watt. Flux densities at any other power level can be obtained by multiplying the tabulated values by the level of interest. The main contribution to error is expected to be the infinite medium assumption inherent in the moments method data. The higher energy fluxes are more accurately predicted than those of lower energy.

### 3.7.4 Nuclear Heating Analysis of Nickel Shell

A peripheral shim to reduce structural nuclear heating has been proposed by LRL to replace part of the radial beryllia reflector of the Tory IIC reactor. The reduction of nuclear heating in the side support structure has been analyzed in a preliminary manner. More detailed calculations will be performed to obtain the accuracy required.

The idealized configuration of the reactor with and without peripheral shims is shown on Figure 90. The non continuous distribution of materials in the side support structure is homogenized for calculation purposes.

The gamma rays that contribute to heating within the side support structure are those produced in the core and those produced in the shims and side support structure from neutron capture. Gamma production from neutron inelastic scattering has been ignored as a minor component.

ALC ACT

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~





~~SECRET RESTRICTED DATA~~

REPORT 58 6

~~ATOMIC ENERGY ACT OF 1954~~

TABLE 12

GAMMA FLUX DENSITIES OUTSIDE TORY IIC REACTOR CORE

Position		Energy Groups						
Radial r (cm)	Axial z (cm)	(Photons/cm <sup>2</sup> /sec/Mev)*						
		E1	E2	E3	E4	E5	E6	E7
124.2	894	3.12/12	7.20/11	2.22/11	8.96/10	3.65/10	9.03/9	1.29/:
152	89	1.13/14	2.51/13	7.73/12	3.07/12	1.24/12	3.04/11	4.27/:
89	254	3.61/13	8.42/12	2.61/12	1.06/12	4.33/11	1.08/11	1.54/:
89	102	8.90/13	2.03/13	6.39/12	2.68/12	1.14/12	2.98/11	4.50/:
89	0	5.37/14	1.19/14	3.67/13	1.44/13	5.80/12	1.40/12	1.94/:
77.5	0	6.69/14	1.49/14	4.63/13	1.83/13	7.36/12	1.79/12	2.51/:
82.5	20	6.27/14	1.40/14	4.30/13	1.70/13	6.81/12	1.65/12	2.29/:
82.5	40	5.67/14	1.26/14	3.89/13	1.53/13	6.12/12	1.49/12	2.07/:
82.5	60	3.98/14	8.93/13	2.76/13	1.10/13	4.42/12	1.08/12	1.52/:
82.5	-40	3.82/14	8.57/13	2.66/13	1.06/13	4.28/12	1.05/12	1.48/:
82.5	-60	2.18/14	4.99/13	1.56/13	6.27/12	2.59/12	6.44/11	9.26/:
112	163	4.23/13	1.04/13	3.32/12	1.39/12	5.84/11	1.51/11	2.25/:
107	123	6.30/13	1.47/13	4.67/12	1.95/12	8.28/11	2.15/11	3.21/:
76.2	228	4.79/13	1.12/13	3.47/12	1.41/12	5.75/11	1.42/11	2.03/:
127	305	2.07/13	4.88/12	1.52/12	6.22/11	2.55/11	6.40/10	9.22/:
190	152	4.40/13	9.9/12	3.07/12	1.24/12	5.06/11	1.27/11	1.82/:
86.4	412	1.54/13	3.55/12	1.10/12	4.43/11	1.80/11	4.46/10	6.34/:
152	762	4.10/12	9.46/11	2.93/11	1.18/11	4.83/10	1.19/10	1.71/:
152	889	3.06/12	7.05/11	2.18/11	8.79/10	3.58/10	8.87/9	1.27/:
152	1020	2.34/12	5.40/11	1.67/11	6.72/10	2.74/10	6.80/9	9.70/:
152	1140	1.88/12	4.34/11	1.34/11	5.42/10	2.20/10	5.47/9	7.78/:

\* N/n = N x 10<sup>11</sup>

DECLASSIFIED IN FULL  
 Authority: EO 13526  
 Chief, Records & Declass Div, WHS  
 Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

~~SECRET RESTRICTED DATA~~

5876

~~ATOMIC ENERGY ACT OF 1954~~

TABLE 13

NEUTRON SPECTRA FOR ONE WATT OF POWER

Position		Flux, $\phi(r, E)$ (n/cm <sup>2</sup> sec Mev )					
Radial r (cm)	Axial z (cm)	E = 0.330	E = 1.096	E = 2.44	E = 3.64	E = 5.43	E = 8.10
89.0	254	1.74/4	4.23/3	1.98/3	2.21/2	1.18/2	..73/1
25.4	472	6.84/3	1.65/3	7.71/2	8.84/1	4.61/1	..57/0
7.63	513	5.75/3	1.39/3	6.48/2	7.41/1	3.88/1	..46/0
152	1140	9.21/2	2.25/2	1.04/2	1.19/1	6.30/0	..67/-1
77.5	0	3.84/5	9.30/4	4.29/4	5.23/3	2.63/3	..71/2
82.5	20	3.59/5	8.68/4	3.98/4	4.91/3	2.45/3	..43/2
82.5	-60	1.13/5	2.75/4	1.27/4	1.50/3	7.71/2	..12/2
82.5	60	2.23/5	5.39/4	2.48/4	3.05/3	1.52/3	..16/2

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

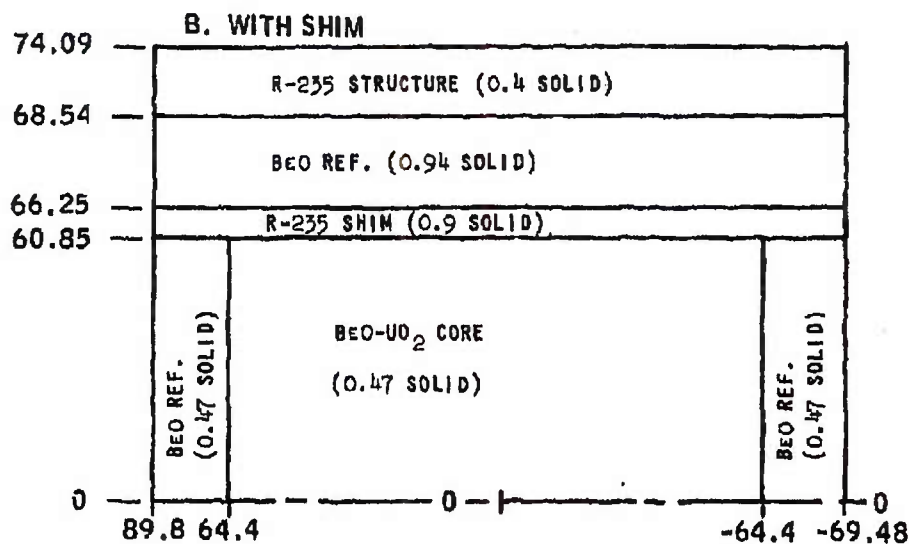
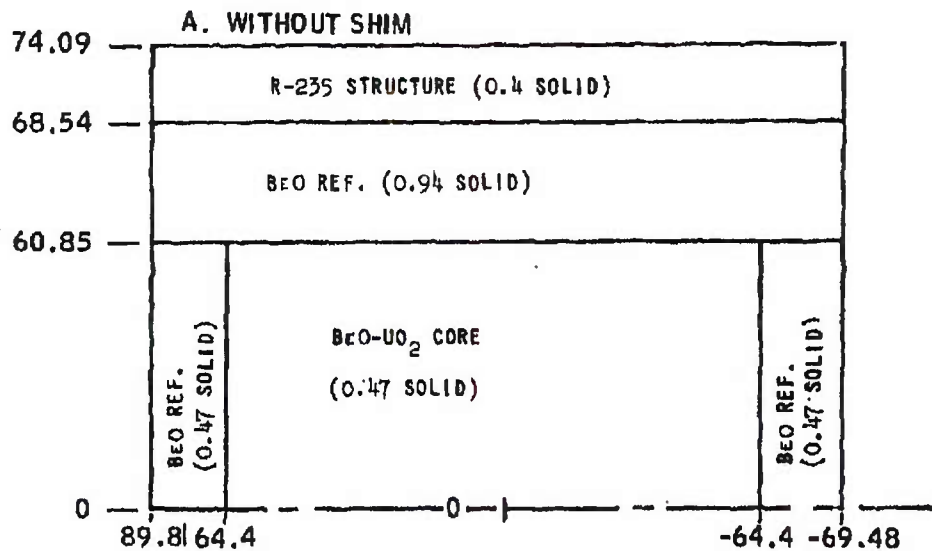
~~SECRET RESTRICTED DATA~~

*Harvard*  
VAN NUYS, CALIFORNIA

REPORT 5 6

ATOMIC ENERGY ACT OF 1954

IDEALIZED CONFIGURATION OF TORY IIC REACTOR  
WITH AND WITHOUT PERIPHERAL SHIMS  
(DIMENSIONS IN CM)



DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

N22C32 ~~ATOMIC ENERGY ACT OF 1954~~

-164-

FIGURE 0



~~SECRET RESTRICTED DATA~~

INT. 5876

~~ATOMIC ENERGY ACT OF 1954~~

The heating due to core gammas was calculated with the Program 04-2. The buildup factor option applied was the semi empirical technique of Kalos (Reference 22) for water followed by iron to represent beryllia followed by R-235.

Neutron fluxes, required for the determination of capture gamma source strengths, were calculated with Zoom, the one-dimensional multi-group, diffusion theory code developed by LRL. Future calculations will be based on leakage values generated by the Angle program. The capture gamma source strengths, the cumulative sum of the product of group flux and group cross sections, are shown in Figure 91 as a function of position for the two design cases.

The evaluation of the heating distribution resulting from the capture gamma source was completed using the Grace II code of Atomics International (Reference 23). Several approximations are involved in the method. The shim and side support structure are represented as infinite slabs, the source strength distributions are represented as exponentials, and Taylor exponential expression for buildup is used. Use of these approximations allows the relationships predicting the heating due to capture gammas to be expressed in a closed form in terms of exponential integrals.

The radial distribution of heating from each gamma component at the maximum heating location is shown in Figure 92. The total gamma heating is shown in Figure 93. While the gamma heating within the side support structure has been appreciably reduced, the total gamma ray heat generation in the shim and support structure is greater than in the corresponding design without shims. More detailed calculations including a Monte Carlo study of the heat generation will be required to assess accurately the value of the shim arrangement.

### 3.7.5 Tory IIC Reflector Nuclear Heating Analysis

The Program 04-2 was used for determining gamma ray flux levels within the side and end reflectors of the Tory IIC reactor. The power distributions, reactor configuration, and reactor composition were taken from Reference 1. Gamma ray heating in the reflectors is calculated directly from the Program 04-2 group fluxes by employing the 10-group energy absorption coefficients of the material at each receiver point examined. Neutron heating, a relatively small fraction of the total nuclear heating contribution, was estimated on the basis of the detailed reflector neutron heating calculations made for the Model MA50 reactor design (Reference 24).

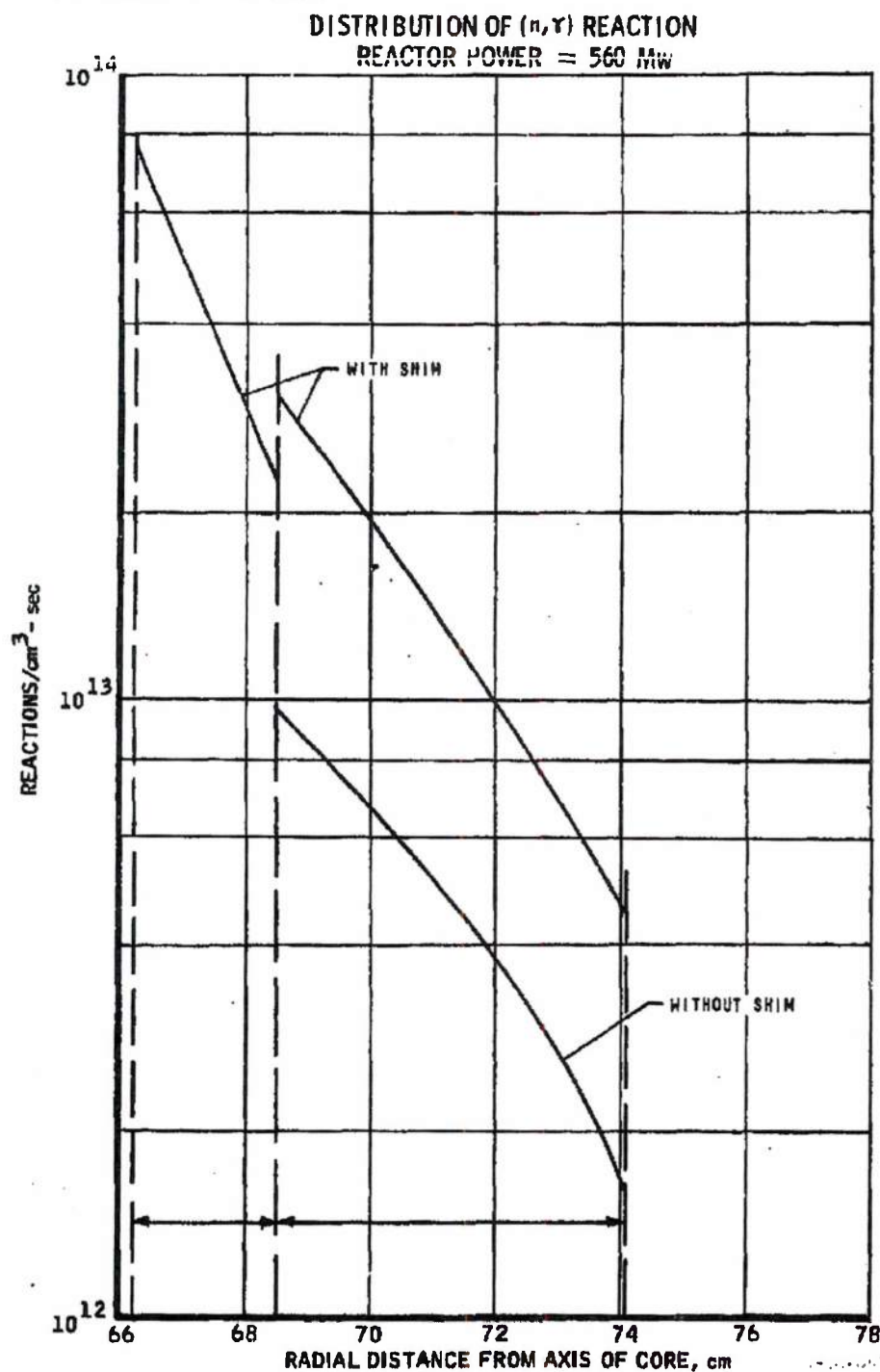
~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~



~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~



~~SECRET RESTRICTED DATA~~

N22C37 ~~ATOMIC ENERGY ACT OF 1954~~

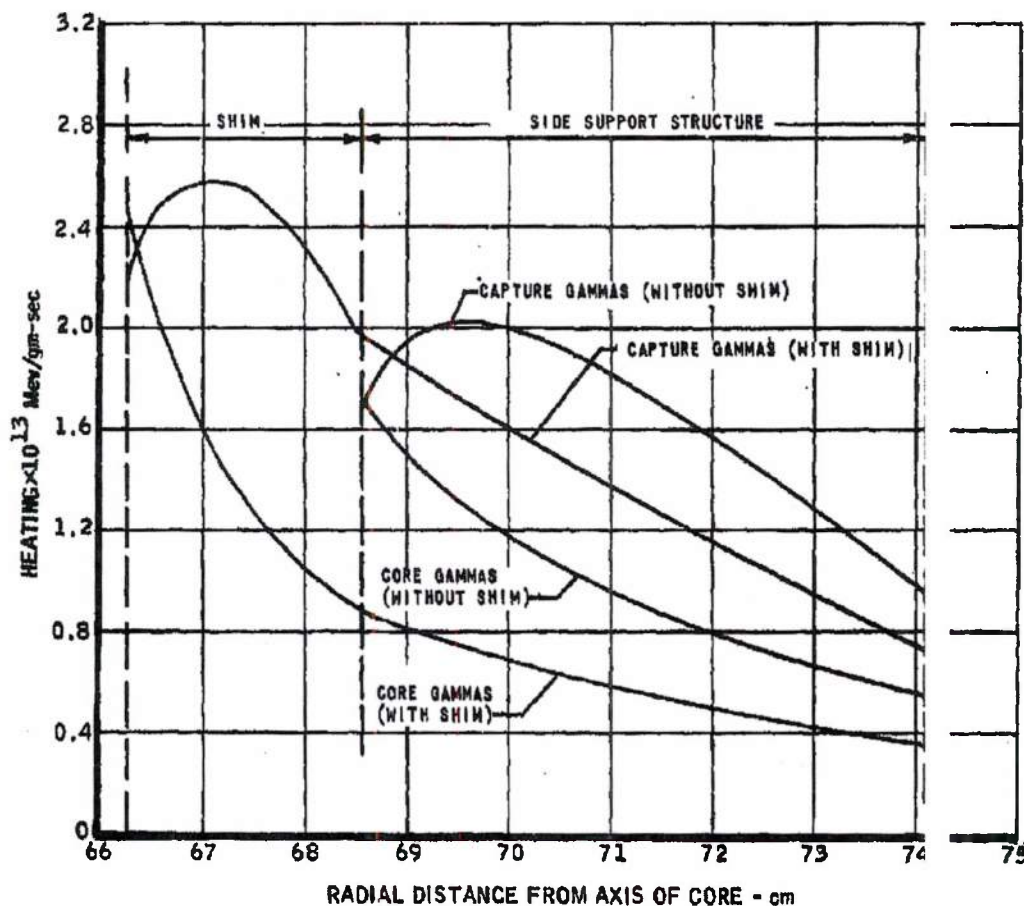
~~SECRET RESTRICTED DATA~~

*The Marquardt Company*  
VAN NUYS, CALIFORNIA

DRT 5876

~~ATOMIC ENERGY ACT OF 1954~~

RADIAL DISTRIBUTION OF HEATING FROM EACH GAMMA COMPONENT  
REACTOR POWER = 560 MW



DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

N22C33 ~~ATOMIC ENERGY ACT OF 1954~~

-167-

FIGURE 92

MAY 29 2015

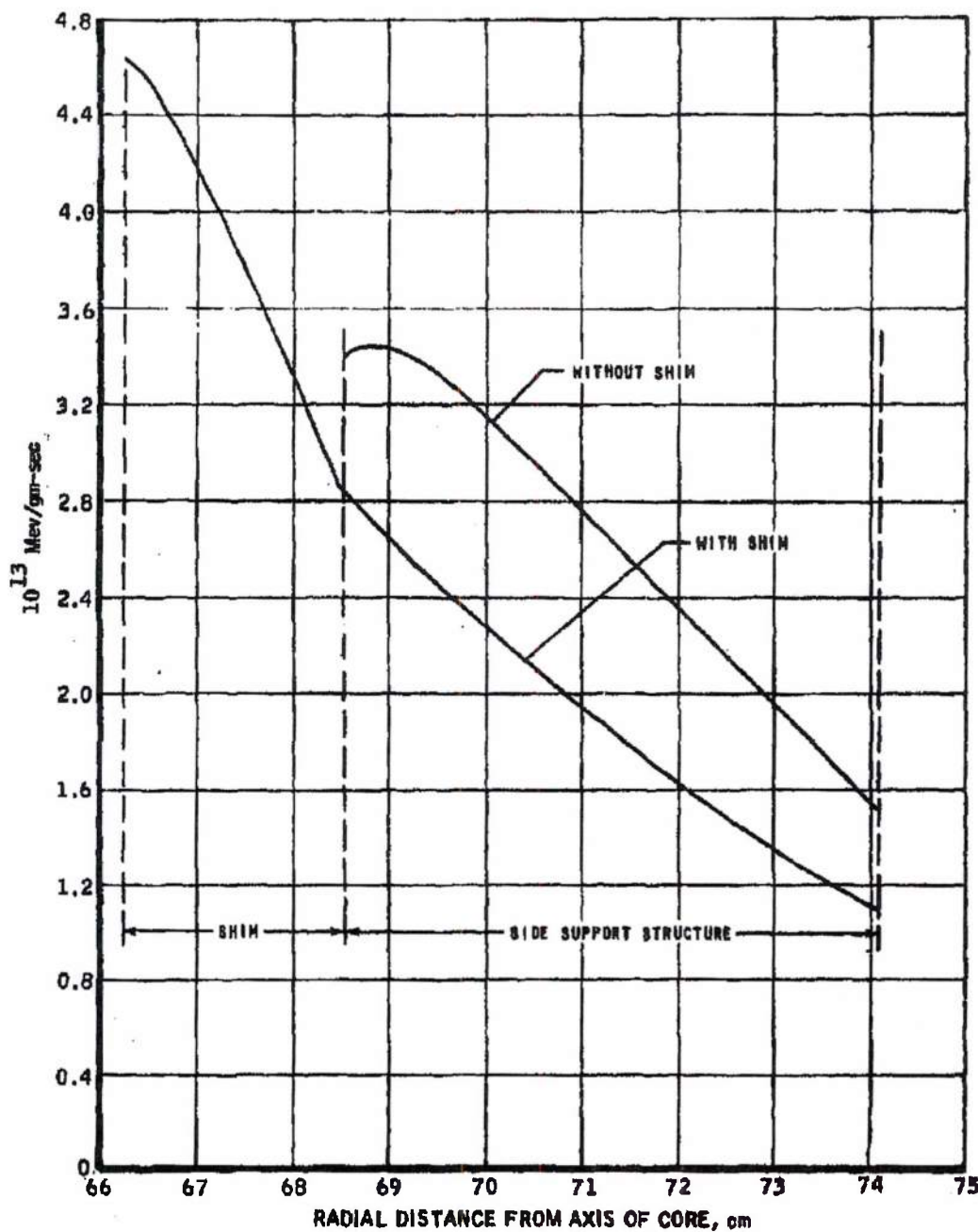
*Marquardt*  
CORPORATION  
VAN NUYS, CALIFORNIA

REPORT 587

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

DISTRIBUTION OF TOTAL GAMMA HEATING  
REACTOR POWER - 560 Mw



~~SECRET RESTRICTED DATA~~

N22C38 ~~ATOMIC ENERGY ACT OF 1954~~

-168-

FIGURE 93

~~SECRET RESTRICTED DATA~~

DET 5876

~~ATOMIC ENERGY ACT OF 1954~~

The axial heating distribution in the end reflectors is shown in Figure 94. The nuclear heating for the side reflector along one radial position is shown in Figure 95. Radial factors for front and rear reflectors are obtained to allow the use of the centerline heating values to estimate heating at any radial and axial position. However, the assumption is made that the radial and axial heating distributions are mutually independent. Because this is not strictly valid, some error will be introduced in the extrapolations. Any points of particular interest can be calculated directly using the Program 4-2 code.

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

MAC AGD

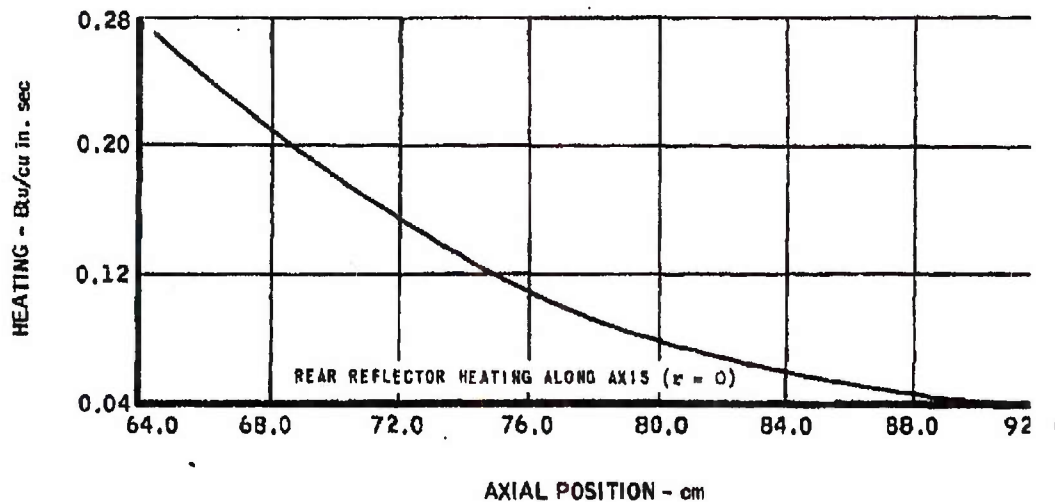
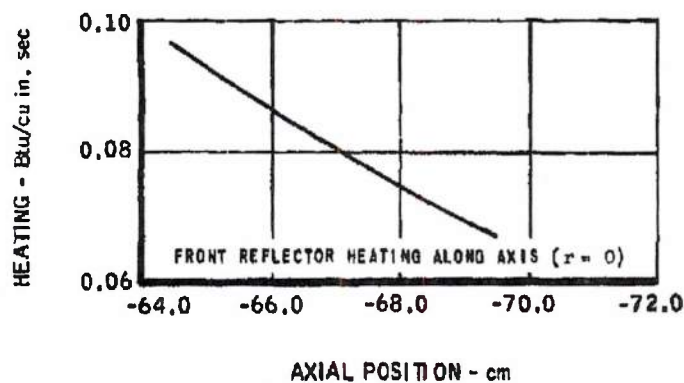
~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~



~~SECRET RESTRICTED DATA~~  
~~ATOMIC RESTRICTED DATA~~

### NUCLEAR HEATING FOR END REFLECTORS



DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

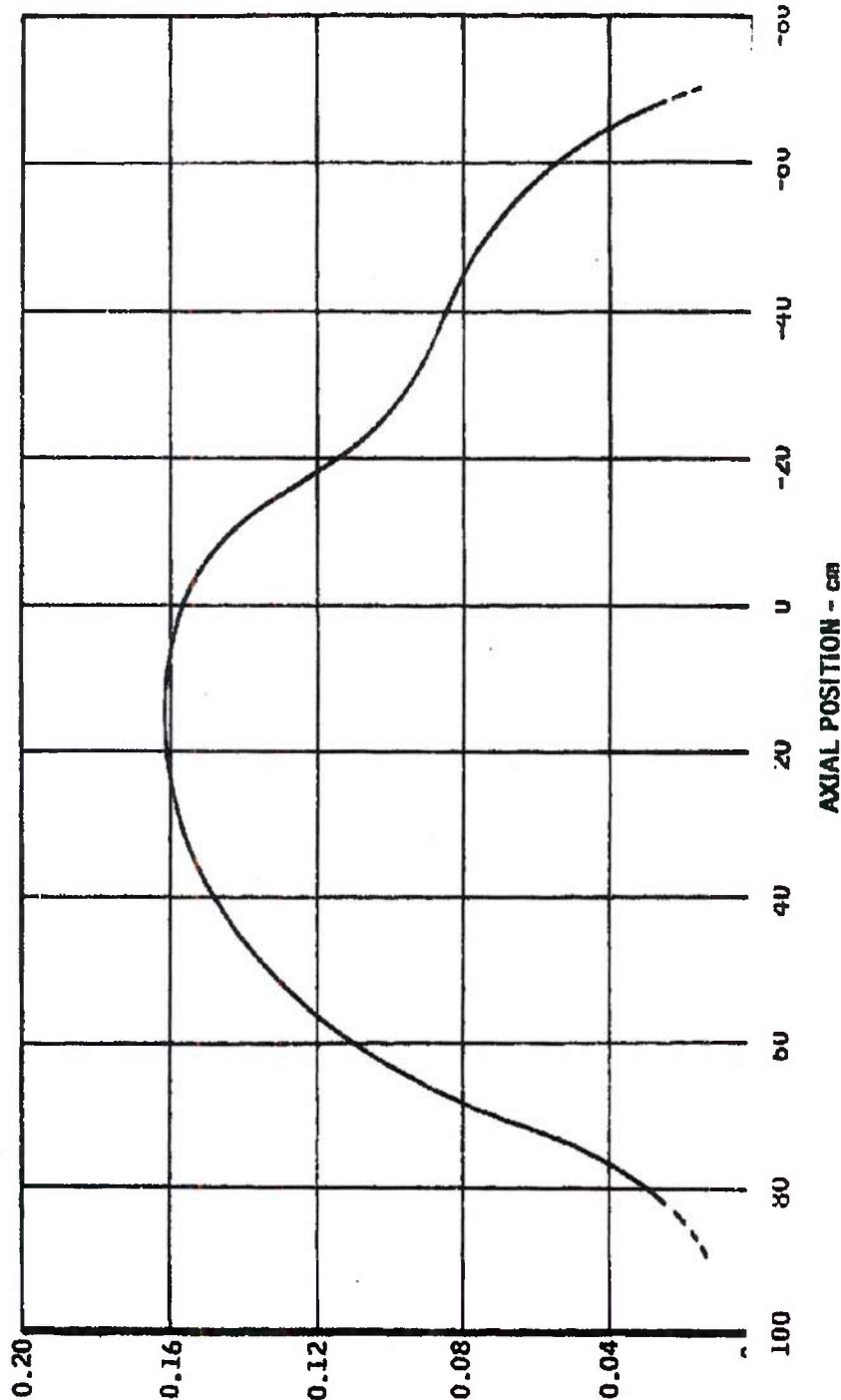
~~SECRET RESTRICTED DATA~~

~~SECRET RESTRICTED DATA~~

NT 5876

~~ATOMIC ENERGY ACT OF 1954~~

NUCLEAR HEATING FOR SIDE REFLECTOR ALONG R=67.62



MAC ACT

~~SECRET RESTRICTED DATA~~

~~N22C45 ATOMIC ENERGY ACT OF 1954~~

- 171 -

FIGURE 95

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

### 3.8 AERODYNAMIC EXPERIMENTS

Design and performance predictions for the nuclear-powered ramjet propulsion system are based upon iterative considerations of material temperature limitations, relationships between allowable reactor temperature and a temperature rise across the reactor, heat addition per unit frontal area of inlet source, and exhaust nozzle performance. In addition, the thrust-to-drag margin is inherently small and is particularly sensitive to inlet installed drag, inlet pressure recovery, and drag penalties associated with inlet bleed and boundary layer diverter systems, as well as nozzle efficiency. The iteration of all these parameters to an accurate prediction of performance is not amenable to analytic methods without certain critical experimental inputs. Consequently, considerable effort was expended in 1961 toward the acquisition of experimental data to aid in the resolution of key aerodynamic problems.

#### 3.8.1 Inlet Model Tests

Negotiations for the inlet test facility were begun in March 1961. Tests were made to the two most promising facilities, Tunnel A of AEDC, Tullahoma, Tennessee, and the Unitary Plan Tunnel at NASA Langley Field, Virginia. Both existing test sections measuring 4 by 4 feet, both facilities are capable of Mach number variation from high transonic to Mach 4.0. The NASA facility was selected over the AEDC facility on the basis of less work load, slightly larger model size, and available tunnel calibrations at desired Mach numbers.

The original program objective was to test the underslung axisymmetric inlet mounted beneath the missile forebody selected by the aerothermodynamics contractor. The test objective was to establish the installed performance of such a system. The configuration performance, such as inlet pressure recovery, bleed requirements, airflow characteristics, and installed drag as a function of angle of attack, yaw, inlet variable geometry condition, and throttle plug position, were desired over the Mach number range from 1.5 to 4.0.

The inlet test program was defined by the Air Force as a joint effort between Marquardt and the aerothermodynamics contractor. In May 1961, a joint meeting was held at Marquardt with representatives of the aerothermodynamics contractor and the Propulsion Laboratory (Aeronautical Systems Division) in attendance. As a result of this meeting it was agreed to expand the test program as follows:

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~



PORT 5876

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

(1) An alternate axisymmetric inlet mutually agreeable to the aerothermodynamics contractor and Marquardt would be fabricated and tested along with the basic inlet. The alternate inlet configuration would be chosen on the basis that it was less sensitive to angle-of-attack and yaw.

(2) Simulation of various longitudinal inlet locations beneath the fuselage would be made. This simulation was accomplished in the model by the addition or removal of inserts in the body ahead of the inlet. A flow field survey was desired by the aerothermodynamic contractor for each simulated inlet position.

(3) Body boundary layer effects upon inlet operation were to be studied in two ways: first, the fuselage boundary layer thickness at the inlet station would be changed by boundary layer trips on the body nose, and/or by the variations in the forebody length as described in the preceding paragraph; second, the body nose ahead of the inlet would be lowered with respect to the inlet. The purpose of this step is to establish the effect of ingestion of fuselage boundary layer upon inlet performance.

Following the finalization of program objectives and scope a second visit was made to the Unitary Plan Tunnel (NASA) in May, and arrangements were made for 3 to 4 weeks of tunnel time beginning about 1 November 1961.

Details of the alternate inlet were established by representatives of the aerothermodynamics contractor and Marquardt in July 1961. The alternate inlet differs from the basic inlet in that the compression fan from the inlet spike is not focused on the lip but rather is spread out and reflected from the cowl inner surface as shown in Figure 30. The alternate inlet (including a revised centerbody) is interchangeable with the basic inlet on the model. It is longer but has a somewhat smaller external cowl angle, and has distributed bleed rather than a localized bleed slot as has the basic inlet.

A detailed test outline was prepared for the revised program and was presented to NASA on 23 August 1961. By this time it was apparent that the 1 November test date could not be met with the existing model fabrication schedule, and it was requested that the test date be moved to about 1 December 1961. NASA consented to the test date change, but objected to the length of the program as affecting test cell occupancy requirements and recommended elimination of all flow field survey runs. A revised test outline was prepared and discussed 17 October 1961 with representatives of the Air Force and the aerothermodynamics contractor in attendance. It was agreed that limited flow survey runs near the inlet design point would be obtained. The drag model would be tested without inlet bleed to determine the effect of bleed flow on the external pressure distributions around the inlet fairings.

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~



~~SECRET RESTRICTED DATA~~

REPORT 58

~~ATOMIC ENERGY ACT OF 1954~~

Figures 96 and 97 show the inlet model during assembly. The model was shipped from Van Nuys 7 November and all checkout procedures and calibrations were accomplished pending installation on 4 December 1961.

Installation was delayed by NASA until 15 December. A checkout on 18 December indicated excessive vibration in the tunnel drive motor. NASA suspended the test program in order to correct the discrepancy.

Testing is scheduled to continue in early January 1962.

### 3.8.2 Exhaust Nozzle Model Tests

The exhaust nozzle model tests conducted during November at the FluidDyne Elk River Aerodynamics Laboratory were performed to verify design and performance prediction assumptions. Experimental data obtained include primary nozzle thrust coefficients, nozzle discharge coefficients, the effect of nozzle secondary (cooling) flow upon the nozzle thrust coefficient, and the nozzle wall pressure distribution to provide nozzle drag load data.

The specific nozzle configurations tested are shown in Figure 98. Additional detailed nozzle contouring information is shown in Figure 99 for the primary nozzles, and in Figure 100 for the forced convection and ejector configurations. As indicated in Figure 99, four of the primary nozzle models consist of truncations of a single contour. In addition to providing thrust, flow, and pressure data on the present optimized primary nozzle configuration (Model FC-3), the testing of additional nozzle lengths of the same basic contour will provide additional verification of the optimized nozzle data and will supply useful data for future installation optimization studies.

The nozzle configurations shown in Figure 100 provided the mechanical geometry to supply secondary (cooling) flow in a manner similar to two of the cooling methods under current consideration. Forced convection cooling of the full length of the nozzle is provided with the Model FC-3 configuration, while in the ejector nozzle the divergent section is film-cooled. The effect of these two methods of cooling on the overall nozzle performance was evaluated experimentally.

The particular static thrust stand upon which these nozzle models were tested is shown in Figure 101. The data recording equipment used in the tests is also shown. Pressures were recorded photographically from mercury column manometer panels and Heise gages. Valve-metered, high-pressure, primary and secondary airflows were measured by using calibrated smooth-approach choked orifices that conformed to the ASME code. Pressure data were recorded

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

-174-

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~CONFIDENTIAL~~

REPORT 5876

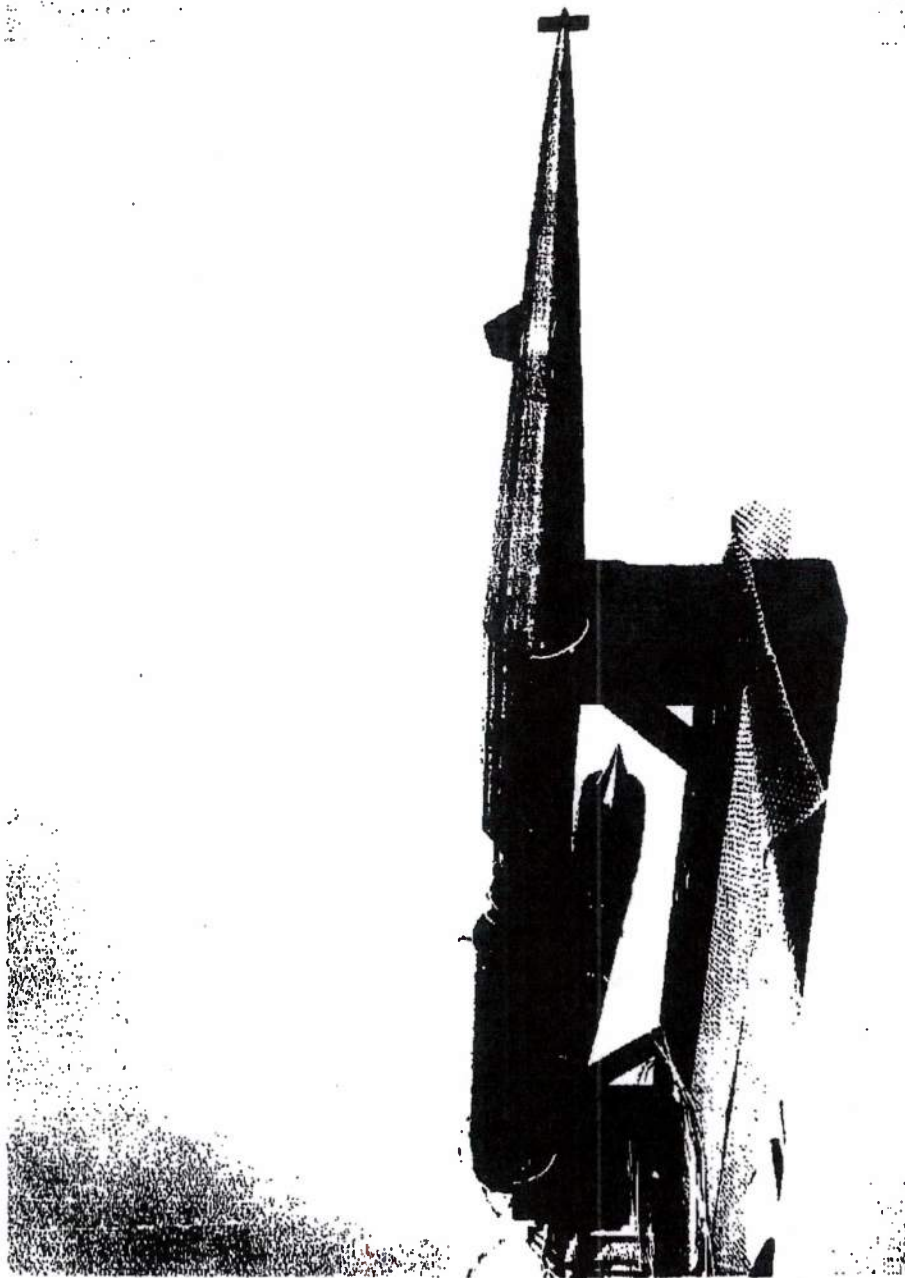


FIGURE 96 - Inlet Model During Assembly

4018-2

MAC A03

~~CONFIDENTIAL~~

-175-

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~CONFIDENTIAL~~

*The Harquardt*  
CORPORATION  
VAN NUYS, CALIFORNIA

REPORT 58



4018-1

~~CONFIDENTIAL~~

#76-

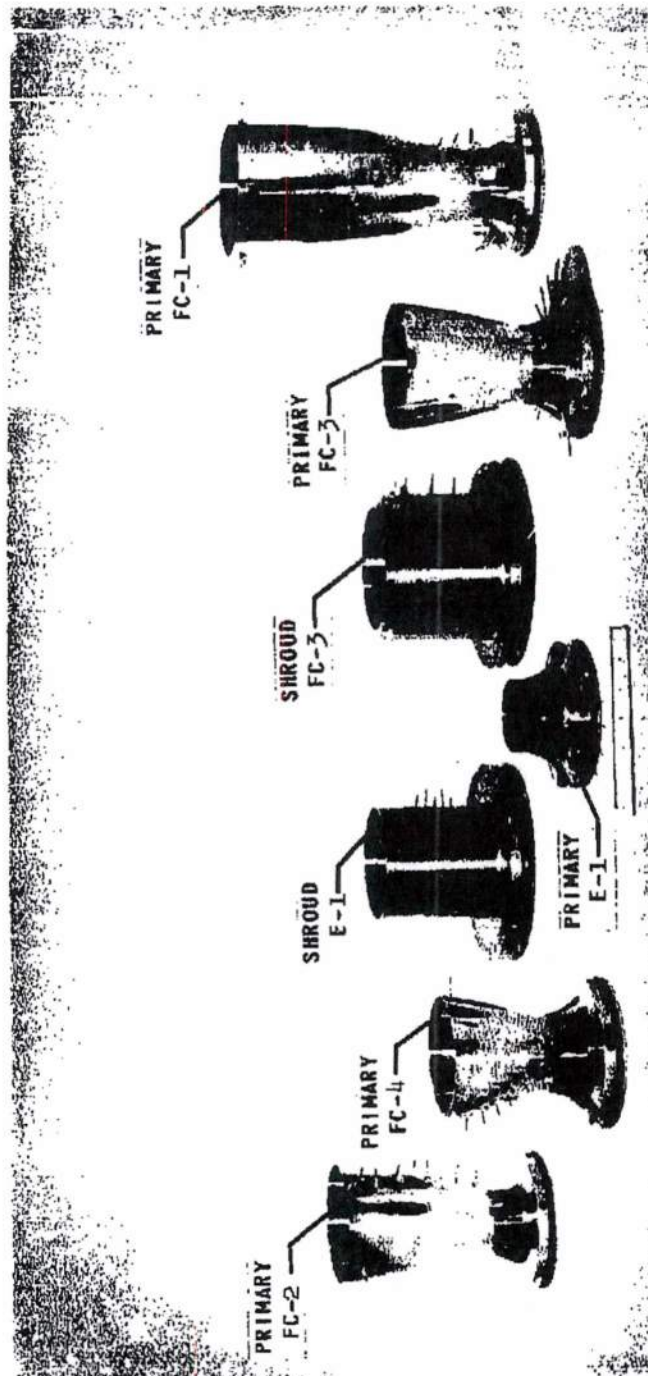
DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015



~~CONFIDENTIAL~~

*Marquardt*  
VAN NUYS, CALIFORNIA

PORT 5876



4084-2

MAC 653

~~CONFIDENTIAL~~

-177-

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015



CONTOURS OF PRIMARY NOZZLES

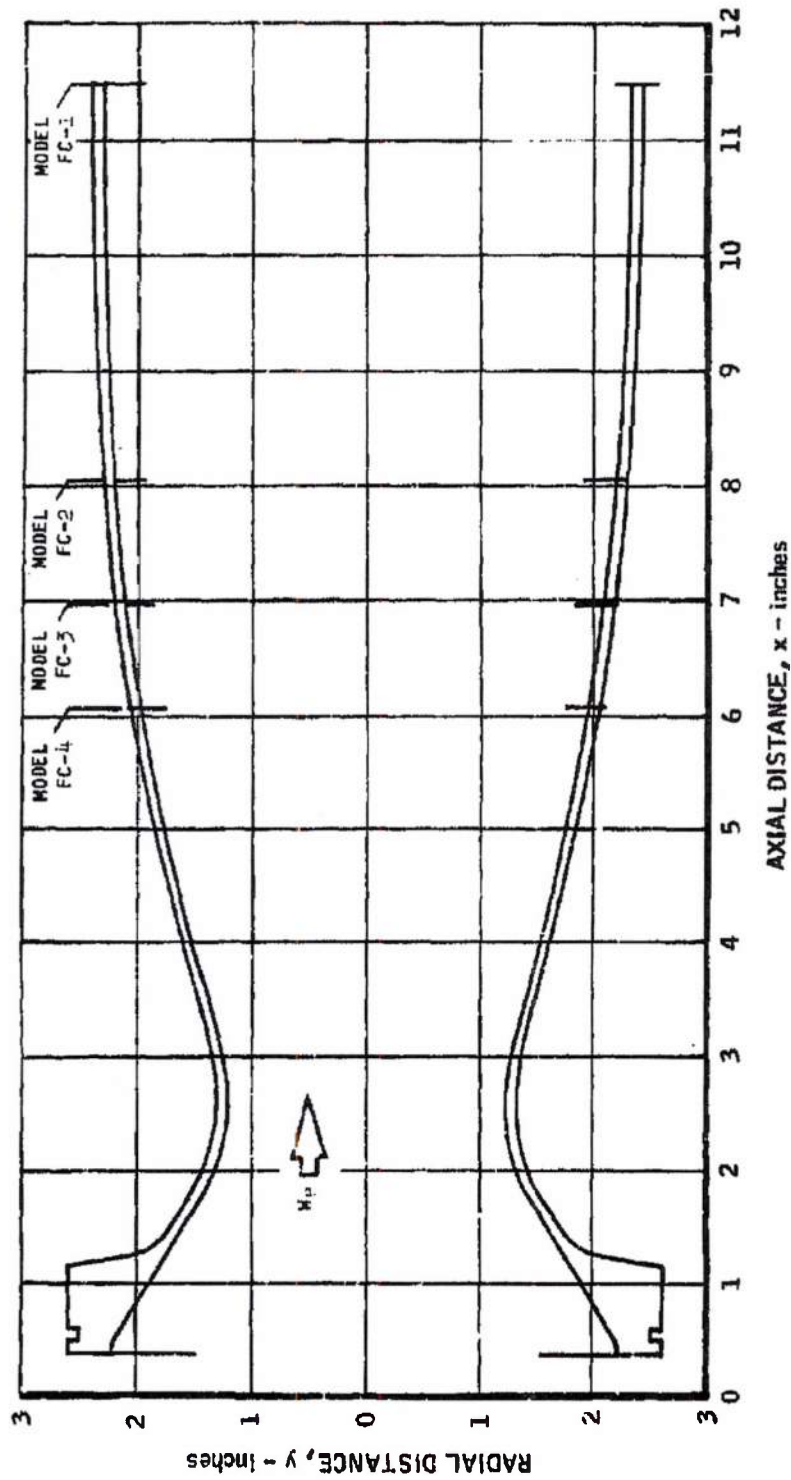


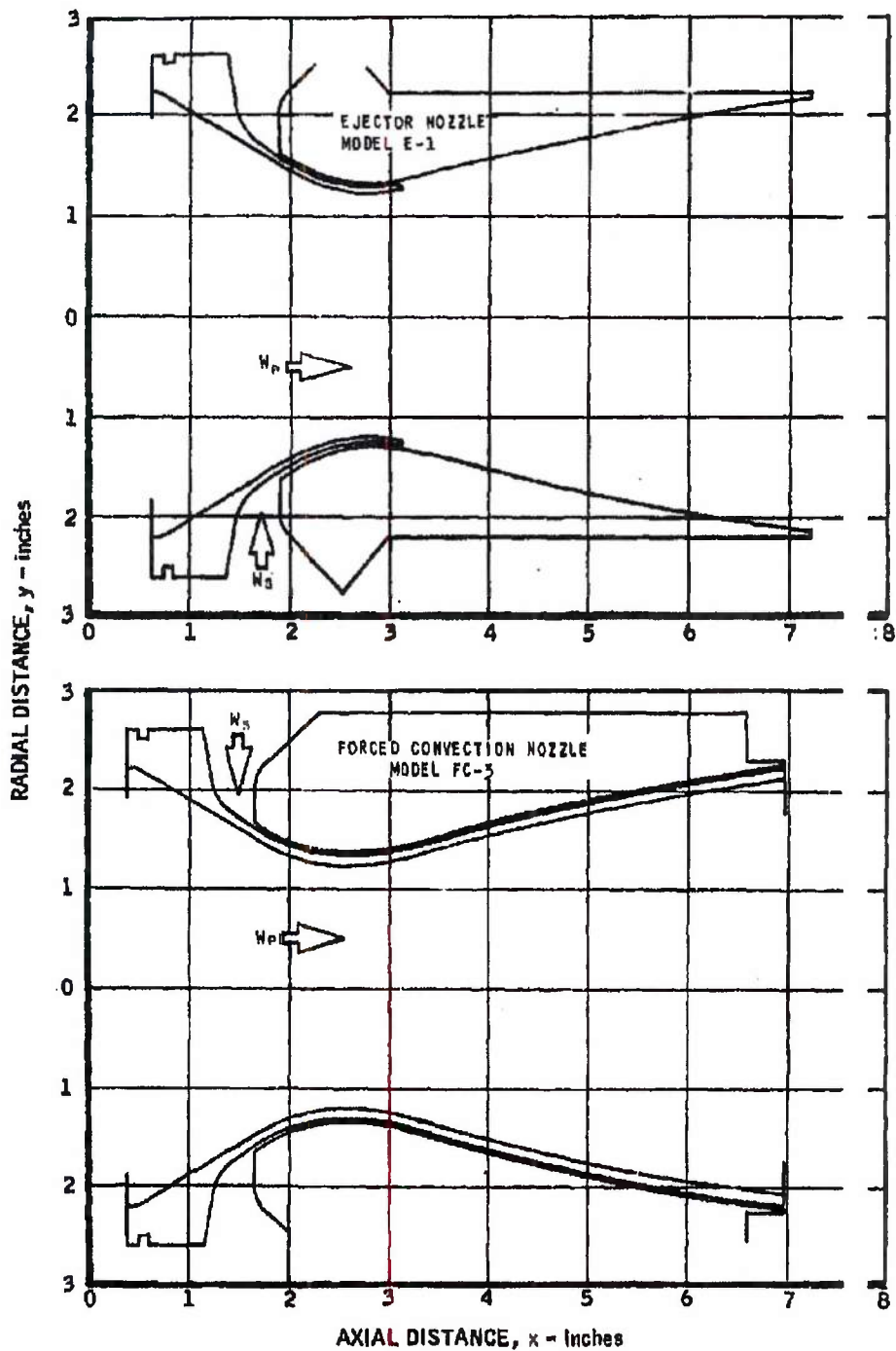
FIGURE 99

~~CONFIDENTIAL~~

THE Marquardt Corporation  
 VAN NUYS, CALIFORNIA

ORT 5876

# CONTOURS OF FORCED CONVECTION AND EJECTOR NOZZLES



RAC 4623

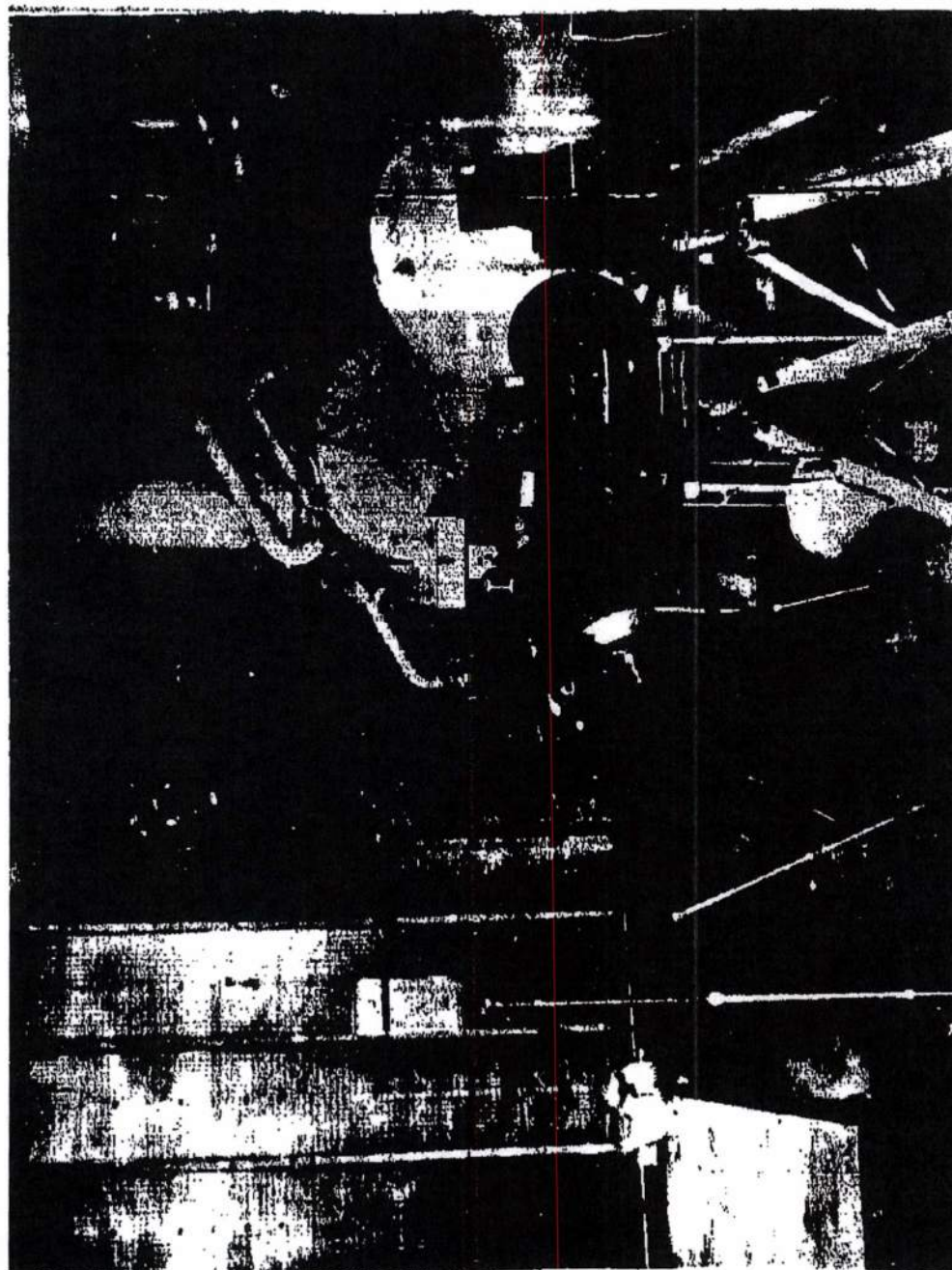
22B11 ~~CONFIDENTIAL~~

FIGURE 100

UNCLASSIFIED

*Marquardt*  
VAN NUYS, CALIFORNIA

REPORT 5 '6



CAN02 1

FIGURE 101 - Static Thrust Facility at Fluidyne Elk River Aerodynamics Laboratory

UNCLASSIFIED



~~SECRET RESTRICTED DATA~~

RI 5876

~~ATOMIC ENERGY ACT OF 1954~~

from various significant locations, such as in the supply piping upstream from the nozzle, along the nozzle walls, and in the exhaust plenum.

The actual thrust of each nozzle was determined by subtracting a measured nozzle drag force from the computed free stream thrust upstream from the nozzle. Each nozzle was secured to the inlet tube by a beam balance assembly and a flexible seal.

The seal prevented leakage of primary flow, and the balance provided the nozzle positioning structure. When flow was introduced through the nozzle, the downstream drag force of the nozzle was measured with a strain balance and an electronic indicator. Because of the flexible seal, force readings were slightly pressure sensitive; therefore, balance calibrations included this variable. Thrust coefficient data from the system were believed to have an absolute accuracy of  $\pm 0.2$  percent.

Tests of the nozzle models were conducted over a pressure ratio ( $P_t/P_a$ ) range of 2 to 30. The secondary flow models were also tested with secondary flows,  $W_s$ , equal to 0, 3.5, and 7.0 percent of primary flow  $W_p$ . The primary inlet total pressure (and primary flow) were retained nominally constant for all runs. The nozzle pressure ratio was varied by controlling the exhaust plenum pressure with a steampowered ejector system.

The thrust coefficient term used in this section is the ratio of the actual thrust to the ideal thrust of the actual nozzle weight flow expanded to the operating exhaust ambient pressure. The coefficient for primary flow alone is equivalent to:

$$C_T = \frac{\text{Actual thrust of primary flow}}{\frac{W_P}{g} V_{P,i}}$$

and with both primary and secondary flows:

$$C_T = \frac{\text{Actual thrust of the combined flows}}{\frac{W_P}{g} V_{P,i} + \frac{W_S}{g} V_{S,i}}$$

where the primary and secondary ideal exhaust velocities were evaluated at the operating total-to-ambient exhaust pressure ratios of each individual flow.

MAC 608

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

-181-

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015



~~SECRET RESTRICTED DATA~~  
~~ATOMIC ENERGY ACT OF 1954~~

The thrust coefficients from tests of the four primary nozzles are shown in Figure 102. Coefficients at design pressure ratio exceeded 0.98 for all four primary nozzles. Model FC-2 demonstrated the highest coefficient that was obtained from the tradeoff of divergence loss and friction as the nozzle length varied. However, this nozzle would be longer than the current installation envelope permits. The Model FC-3 yielded a thrust coefficient of 0.983 at the optimized, cold flow, design pressure ratio of 20.3. In the separated regime, as area ratio increased, the expected decrease in thrust coefficient occurred.

With secondary flow, the overall thrust coefficient (as defined in the second equation above) decreased because of the pressure drop in the secondary flow passage and the momentum loss resulting from the convergent secondary exhaust passage. The overall thrust coefficient of Model FC-3 decreased from 0.983 to 0.977 when secondary flow was introduced, as shown in Figure 103. Further, the thrust coefficient was independent of secondary flow variation except when the nozzle was highly separated. In this condition, flow separation was inhibited by increasing secondary flow, and a decrease in thrust coefficient resulted.

Without secondary airflow, the design-point thrust coefficient of the ejector configuration was 0.981, as shown in Figure 104. This value is slightly less than that achieved for the Model FC-3 configuration, and is the result of the wall discontinuity in the primary flow of the ejector configuration. When ejector secondary flow was introduced, the thrust of the primary flow increased as the discontinuity was smoothed out, and the thrust of the secondary flow increased above that of the Model FC-3 because of the additional momentum rise with supersonic expansion. These two small increases appeared to equal the secondary flow pressure drop, and mixing losses for the overall thrust coefficient remained unchanged at 0.981.

In the separated regime with the ejector nozzle, the secondary flow reduced separation and improved the thrust coefficient. When the secondary flow was 3.5 percent of primary flow, the thrust improvement was greater than the flow at 7.0 percent of primary, indicating that an optimum secondary flow existed and was bracketed by test data. However, the cooling requirement of secondary flow is much more important than the performance advantage at greatly over-expanded operating pressure ratio conditions.

The thrust coefficients defined by force measurement were verified using the nozzle wall pressure distribution to define the nozzle drag. The wall pressure distribution resulting from the primary nozzle flows is shown plotted

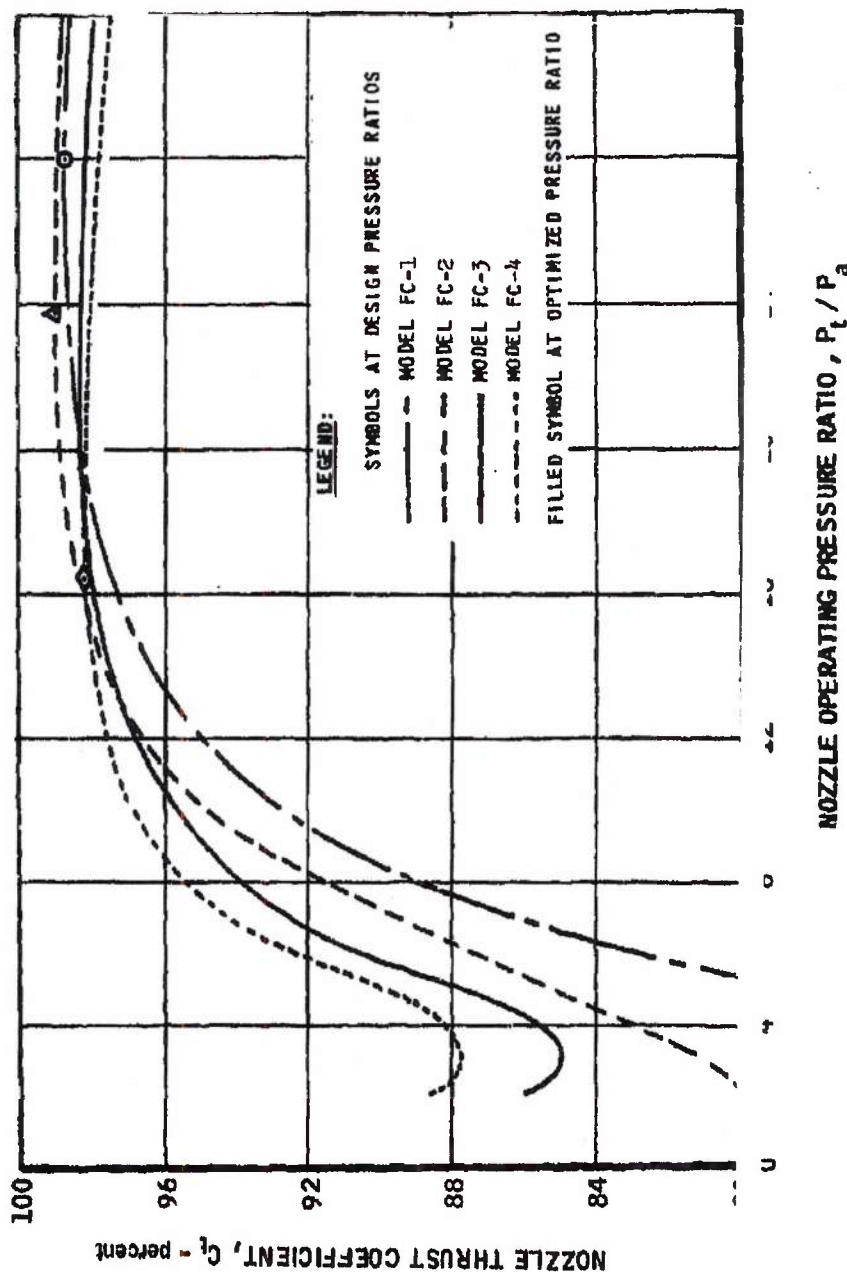
~~SECRET RESTRICTED DATA~~  
~~ATOMIC ENERGY ACT OF 1954~~

~~CONFIDENTIAL~~

THE *Marquardt*  
CORPORATION  
VAN NUYS, CALIFORNIA

ORT 5876

THRUST COEFFICIENTS FROM TESTS OF PRIMARY NOZZLES



MAC AGS

22B12 ~~CONFIDENTIAL~~

-183-

FIGURE 102

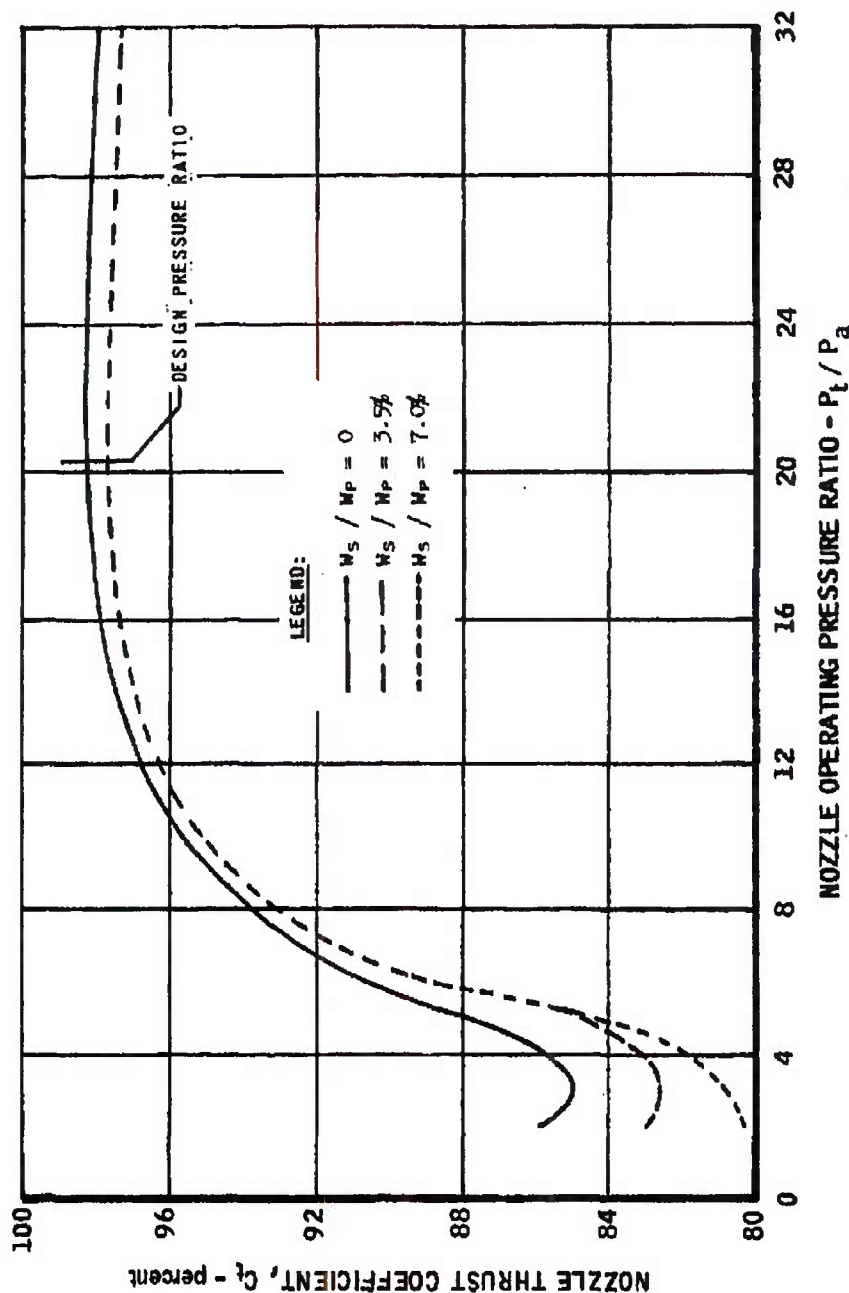
DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

CONFIDENTIAL

*The Marquardt*  
 COMPANY  
 VAN NUYS, CALIFORNIA

REPORT 587

THRUST COEFFICIENT OF FORCED CONVECTION NOZZLE (MODEL FC-3)



MAC 1473

22B13 CONFIDENTIAL

-184-

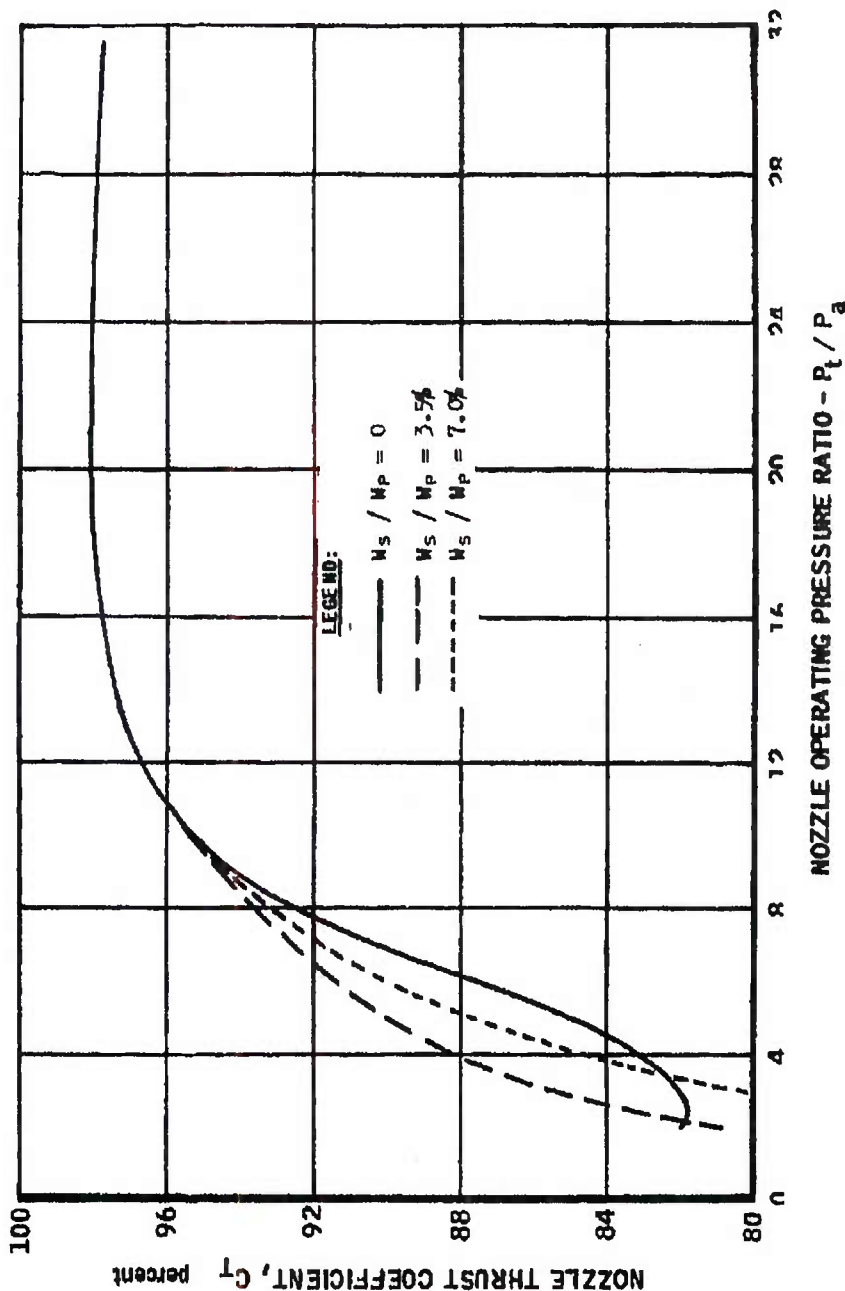
DECLASSIFIED IN FULL FIGURE 103  
 Authority: EO 13526  
 Chief, Records & Declass Div, WIS  
 Date: MAY 29 2015

~~CONFIDENTIAL~~

*The Marquardt*  
VAN NUYS, CALIFORNIA

MT 5876

THRUST COEFFICIENT OF EJECTOR NOZZLE (MODEL E-1)



MAC 4608

22B14

~~CONFIDENTIAL~~

-185-

DECLASSIFIED IN FULL

Authority: EO 13526

Chief, Records & Declass Div, WHS

Date: MAY 29 2015

FIGURE 104



~~SECRET RESTRICTED DATA~~

REPORT 5 6

~~ATOMIC ENERGY ACT OF 1954~~

against expansion ratio in Figure 105. The composite data shown are the average of data taken from each of the four primary models. Very little variation in local wall pressure ratio existed between models. The deviations from two-dimensional flow that are shown were consistent with expected trends in axially symmetric flow.

Figure 106 is a shadowgraph of the exhaust flow from Model FC-3 at design pressure ratio. The weak shocks visible in the exit were generated in the nozzle wall from a slight reduction in local expansion rate along the wall that coalesced into the weak shocks visible at the exit. This condition indicated that the wall curvature approximately 3 inches downstream from the throat was slightly excessive. The wall pressure distribution contained no apparent local variation, which tends to indicate that the shocks did not retain their single discontinuity identity completely upstream to the wall. Very weak shocks in the divergent section of a propulsion nozzle have no significant effect on the thrust efficiency of the nozzle. The high thrust coefficient of the subject nozzle verifies this.

The low nozzle contour curvature through the throat region results in a discharge coefficient of 0.991. Values of discharge coefficient computed from data taken from all five primary nozzle configurations were essentially identical, because all convergent contours were identical. No particular trend of variation with pressure ratio was apparent, indicating that the discharge coefficient is constant over the complete operating range.

Results of the experimental program are thus quite encouraging. Nozzle thrust coefficients of 98 percent or better have been achieved for both forced convection and ejector configurations. Further, it is anticipated that full scale nozzles will yield even better thrust coefficients, because the performance will improve with Reynolds number. Also, improved performance can be expected for the ejector configuration, because the primary nozzle liner thickness in the model was greatly out of proportion to the nozzle throat diameter and created a relatively large disturbance in the nozzle flow field. These results will be further studied to indicate the desirability of nozzle contour changes, pressure losses in the secondary cooling systems, and nozzle installation optimization.

### 3.8.3 Aerodynamic Coupling Tests

#### General

The purpose of the aerodynamic coupling test was to investigate suspected problem areas that were revealed by analytical studies.

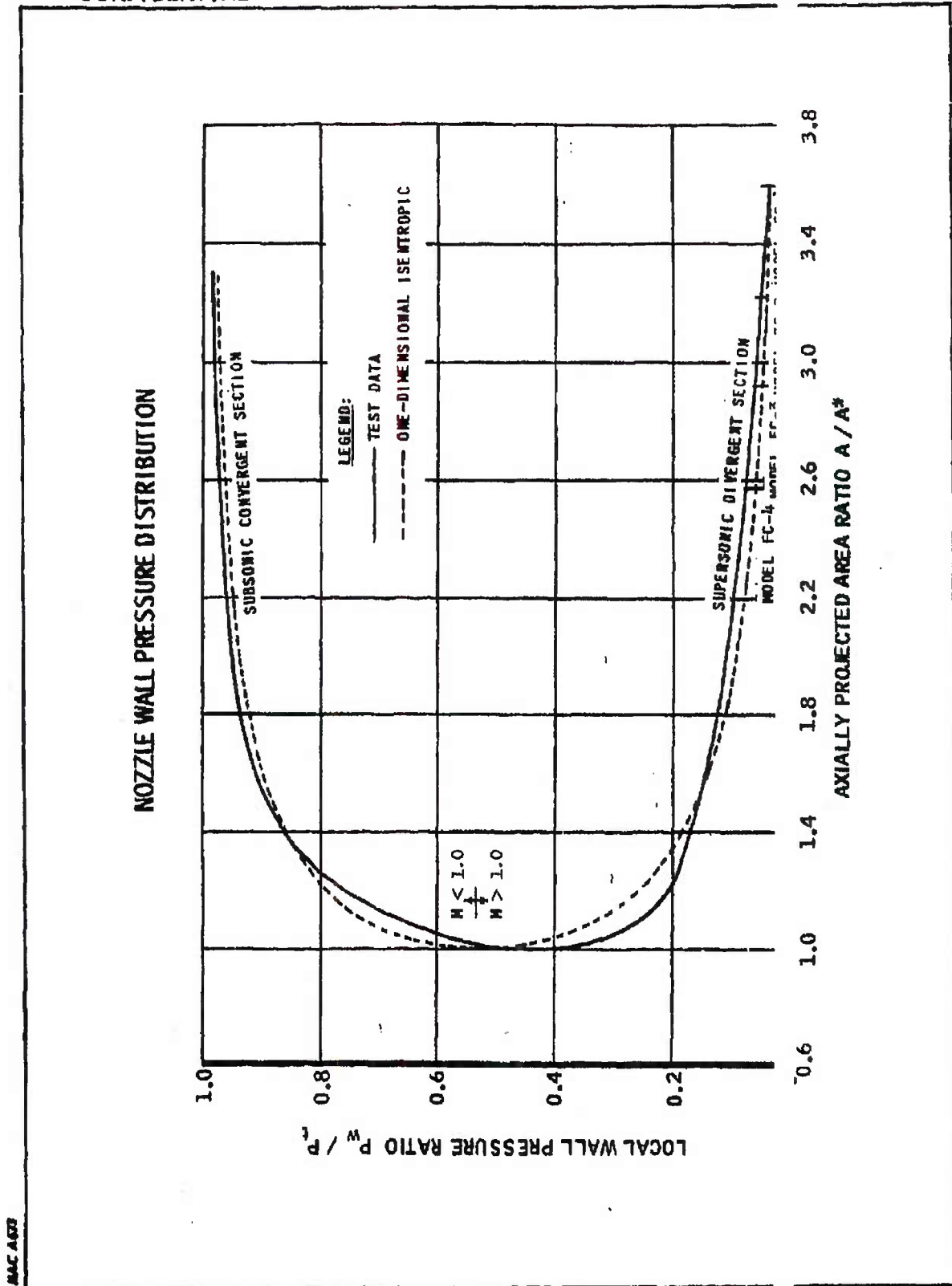
~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

-186-

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~CONFIDENTIAL~~



~~CONFIDENTIAL~~

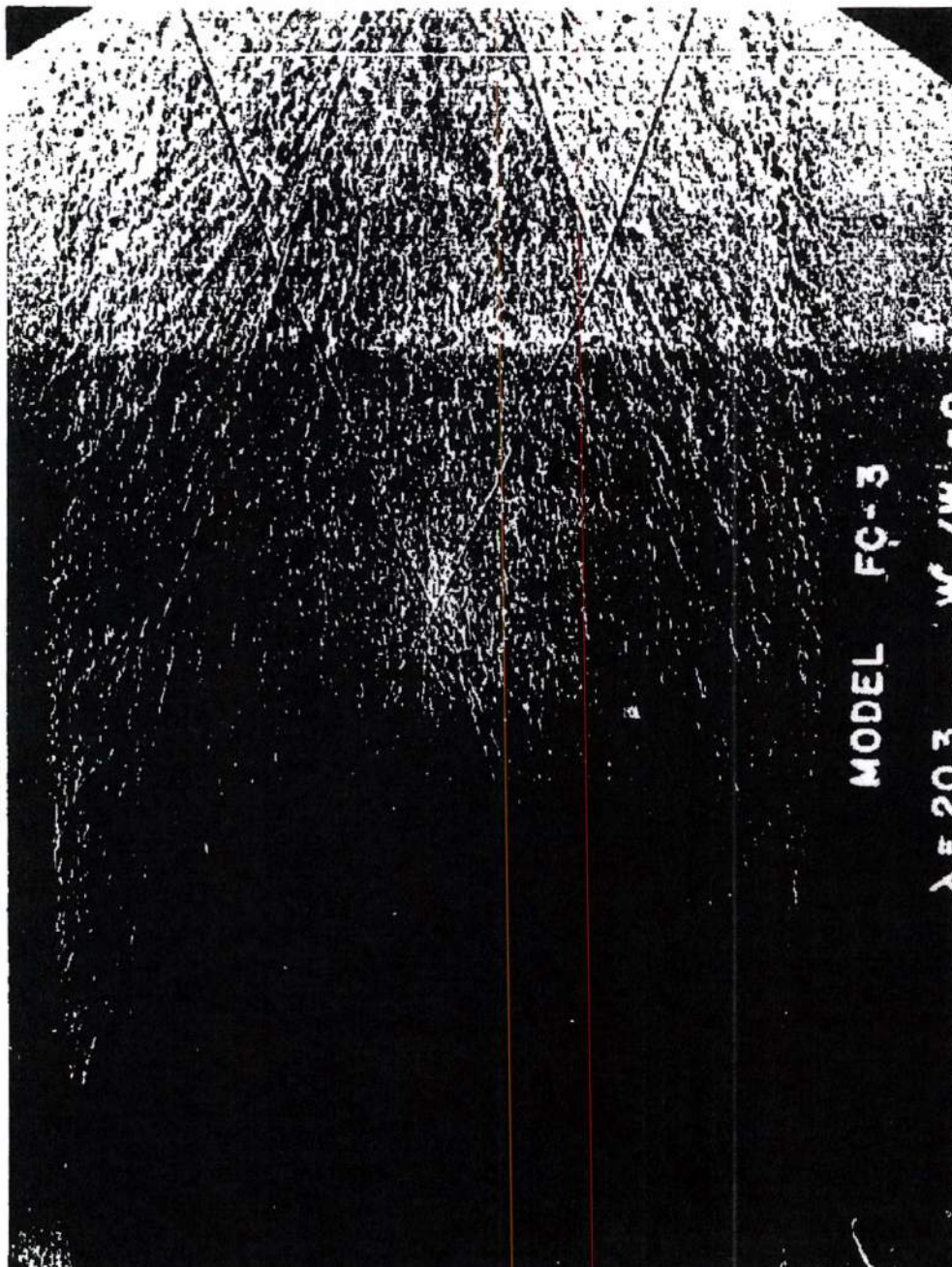


FIGURE 106 - Shadowgraph of Exhaust Flow from Forced Convection

C4074-2

MAC AGS

~~CONFIDENTIAL~~



~~SECRET RESTRICTED DATA~~

PORT 5876

ATOMIC ENERGY ACT OF 1954

The primary areas of investigation are discussed below:

(1) The results of rather tedious hand calculations to determine the effect of typical diffuser exit profiles on the performance of the nuclear ramjet engine were presented in Reference 25. For this study, the method of approach involved satisfying mass and momentum relationships while maintaining the reactor exit static pressure at the undisturbed or uniform flow value. From early single tube analyses, it was concluded that the reactor overall pressure drop probably would be a controlling factor in determining the flow-straightening ability of the reactor. A simplified method of analysis, which considered neither mass nor momentum, was then made to determine qualitatively the effect of pressure drop and flow straightening. The results of the simplified study (reported in Reference 7), in conjunction with the previous analysis of Reference 25, lead to the comparison of profile straightening parameters presented in Figure 107.

The analyses indicate that the reactor is an effective flow straightener; i.e., the tube weight flow perturbations due to an imposed total pressure profile are reduced. In particular, these studies indicate that local reactor wall temperature increases due to tube weight flow reduction with imposed pressure profile are small and tolerable. The primary purpose of the aerodynamic coupling test was, therefore, to provide an experimental verification of the analytical predictions.

(2) At the reactor rear face, pressure distortions, and hence, tube weight flow perturbations may result from the multiple flow passage discharge, structural blockage, and flow mixing. In addition, the convergent portion of the exit nozzle may impose a further static pressure distortion if physical coupling is too close. Attempts to evaluate these items by literature survey and analytical predictions were not satisfactory. Thus, the second purpose of the aerodynamic coupling test was to provide experimental data on pressure distortions at the rear face of the reactor.

(3) A third area, later considered, was the determination of reactor noise generation levels. It was anticipated that noise measurement obtained for a representative reactor configuration would give some insight into problems of this nature that might exist in the full scale reactor.

Thus, this type of test and associated hardware could produce data that would aid directly in nuclear propulsion system analysis and would be a valuable tool in verifying analytical models and concepts.

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

MAC 107

~~SECRET RESTRICTED DATA~~

ATOMIC ENERGY ACT OF 1954



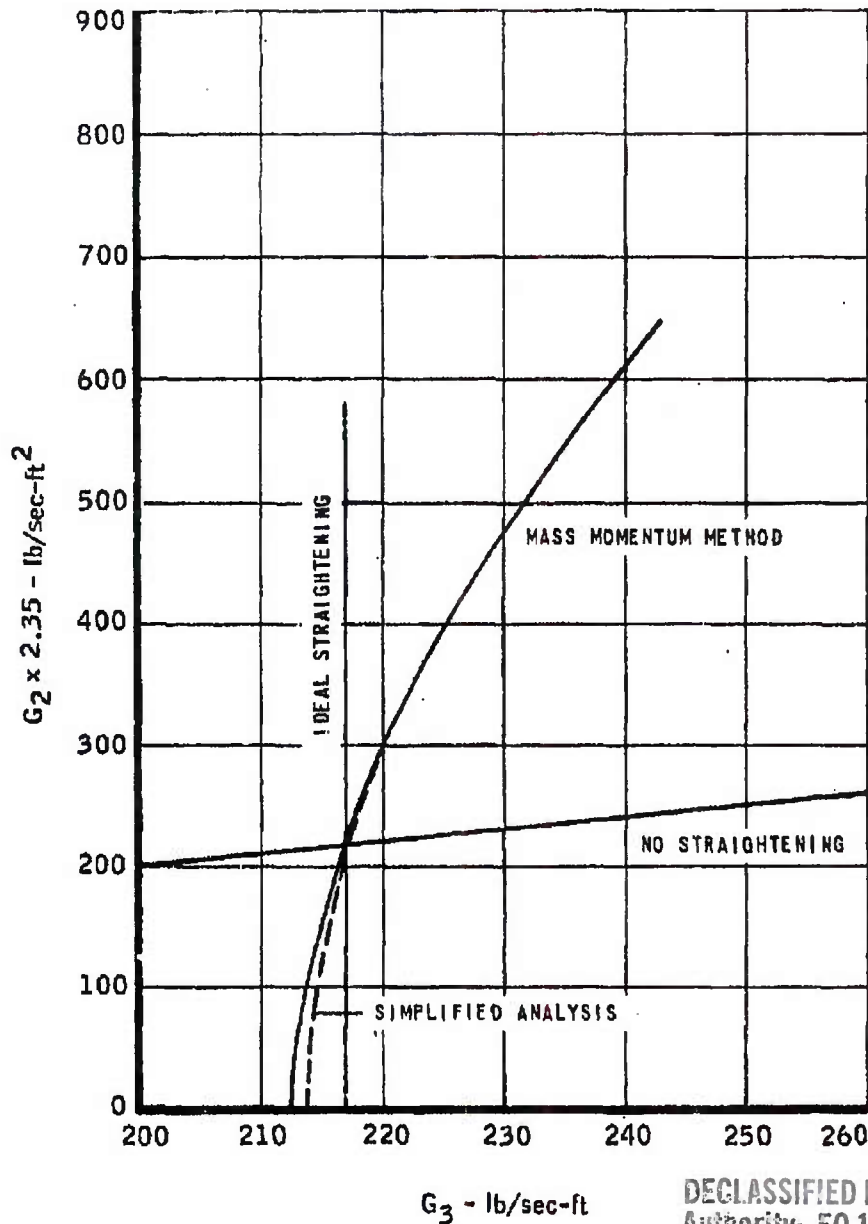
~~SECRET RESTRICTED DATA~~

*The Marquardt*  
VAN NUYS, CALIFORNIA

REPORT 58

~~ATOMIC ENERGY ACT OF 1954~~

### COMPARISON OF PROFILE STRAIGHTENING CHARACTERISTICS MA50XA-1 AT DESIGN POINT



DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

~~SECRET RESTRICTED DATA~~

ORT 5876

~~ATOMIC ENERGY ACT OF 1954~~

#### Aerodynamic Coupling Test Hardware

The use of a simulated full-length reactor section was predicated on the belief that only with a full-length section could a realistic reactor pressure drop be obtained. A test section diameter was established at 18 inches for the following reasons:

(1) A test section of this size would provide a centrally located Tory IIC standard unit cell free from any duct wall airflow effects.

(2) A test section of this size would provide a simulated control rod and tie rod unit cell that at some later date could be evaluated with the attached upstream control rod drive rod and actuator mechanisms. It was felt that the airflow blockage of the actuator mechanisms, which were not fixed in geometry at the time of coupling hardware design, could not be simulated in a duct diameter smaller than 18 inches.

(3) Airflow requirements for a test item of a larger diameter would compromise desired operating times.

The aerodynamic flow lines of the Tory IIC reactor were simulated as closely as possible; however, some modifications in construction and assembly methods were required to facilitate instrumentation and to reduce hardware costs.

The simulated Tory IIC reactor section or module, which is referred to as the "tube bundle," is constructed of aluminum hexagonal tubes of the size and arrangement similar to the Tory IIC. These tubes are held longitudinally by two end retainer plates secured by rods that pass through the radial segment blocks. The radial segment blocks, which restrain the tube bundle laterally, are further secured by steel strapping around the circumference. Figure 108 is a photograph of the test item partially assembled. Figure 109 is an end view of the assembled tube bundle showing the steel strapping. The large tube is the control rod tie tube. The aft retaining plate and an instrumentation plate had not yet been installed. Figure 110 is a photograph of the aft plate showing the general arrangement of instrumentation and the size of tubes used. Figure 111 shows the completed tube bundle assembly installed in the 18-inch duct. This view shows the front face instrumentation and the simulated control rod inserted into the control rod tie tube.

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

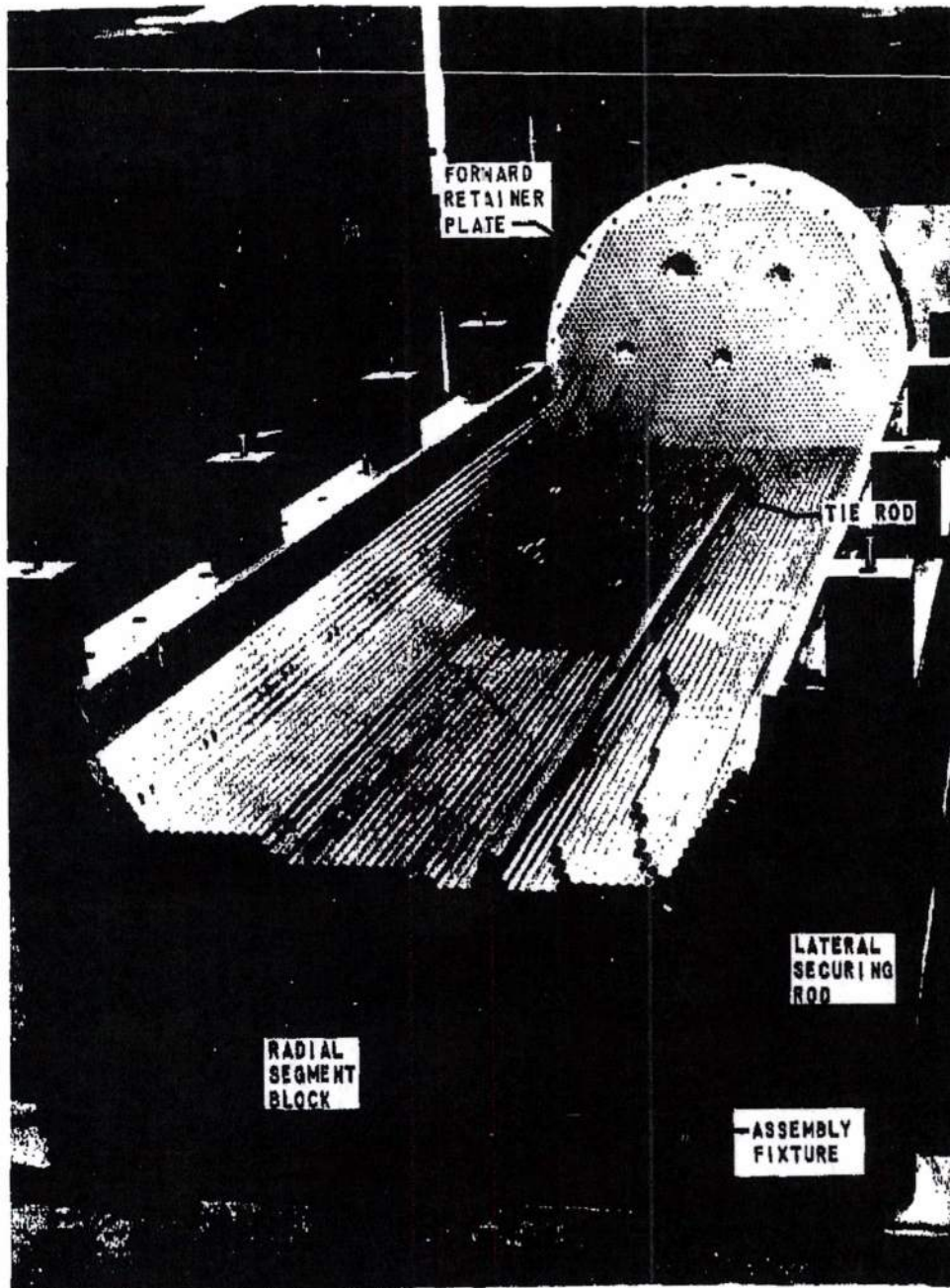
~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

~~CONFIDENTIAL~~

*The Marquardt*  
VAN NUYS, CALIFORNIA

REPORT 76



3946-2

FIGURE 108 - Buildup of Simulated Reactor Segment  
for Aerodynamic Coupling Test

~~CONFIDENTIAL~~

-192-

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015



~~CONFIDENTIAL~~

THE *Marquardt*  
CORPORATION  
VAN NUYS, CALIFORNIA

ONT. 5876

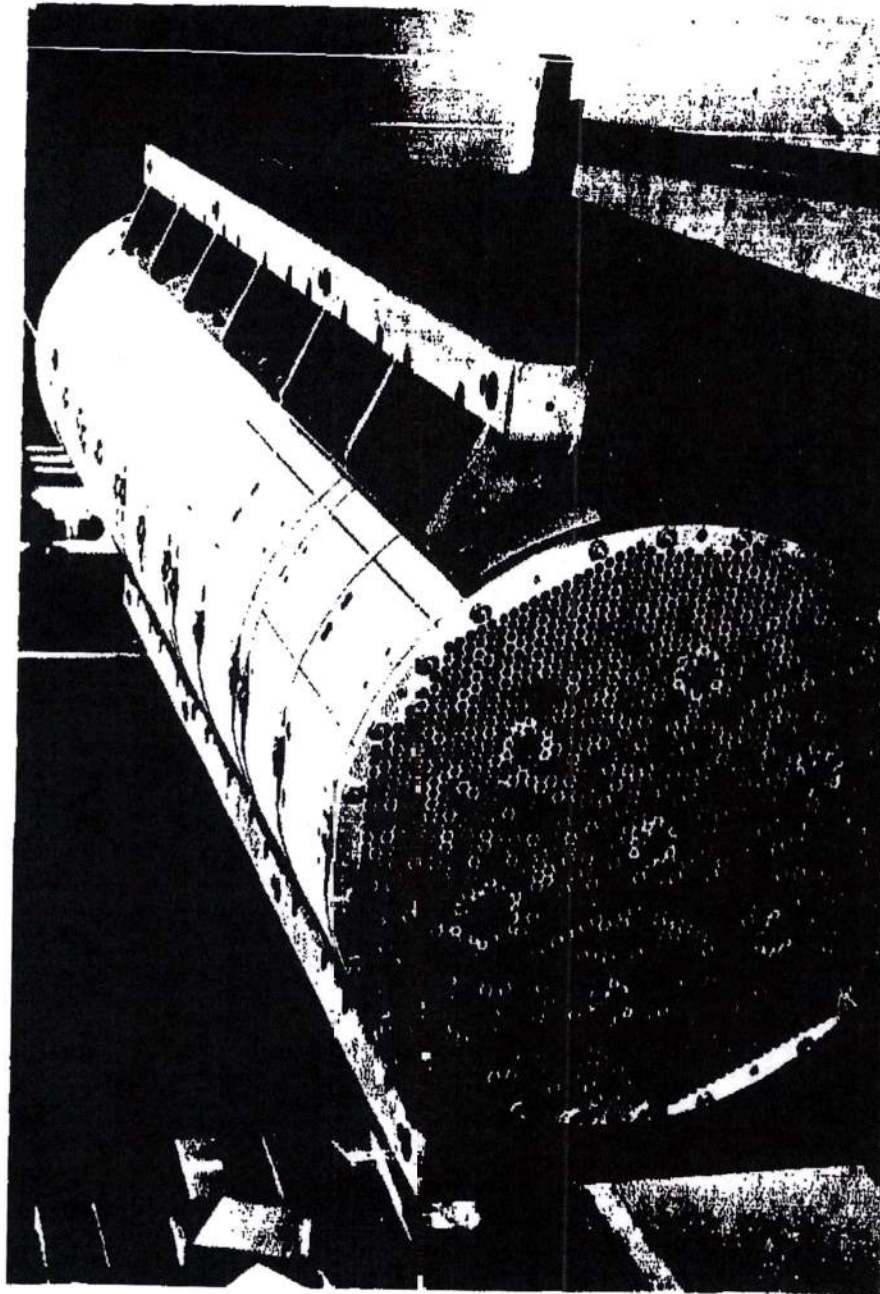


FIGURE 109 - Completion of Buildup of Tubes in Simulated Reactor Segment

3946-5

MAC 1527

~~CONFIDENTIAL~~

-193-

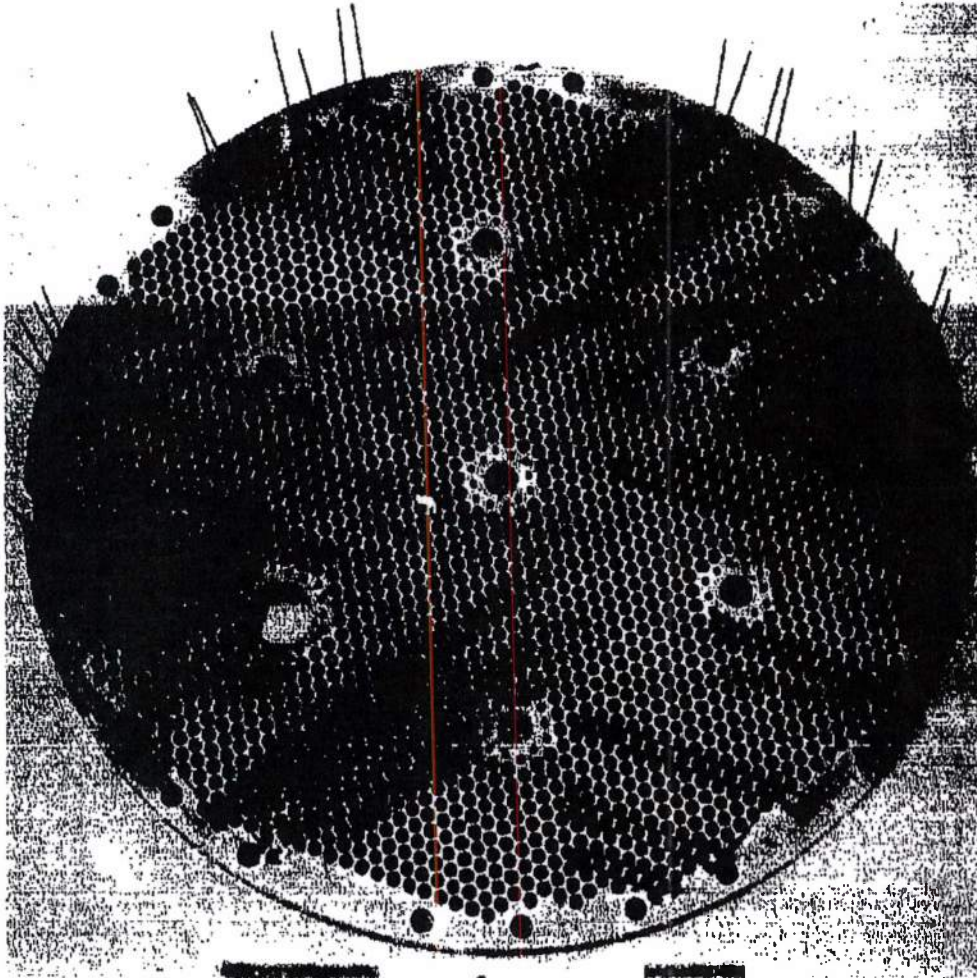
DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015



~~CONFIDENTIAL~~

*The Marquardt*  
CORPORATION  
VAN NUYS, CALIFORNIA

REPORT 5 16



3946-4

FIGURE 110 - Aft Plate with Instrumentation and Tubes Used  
to Build Up Simulated Reactor Segment

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

MAC 167

~~CONFIDENTIAL~~

~~CONFIDENTIAL~~

*The Marquardt*  
VAN NUYS, CALIFORNIA

R. NET 5876

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

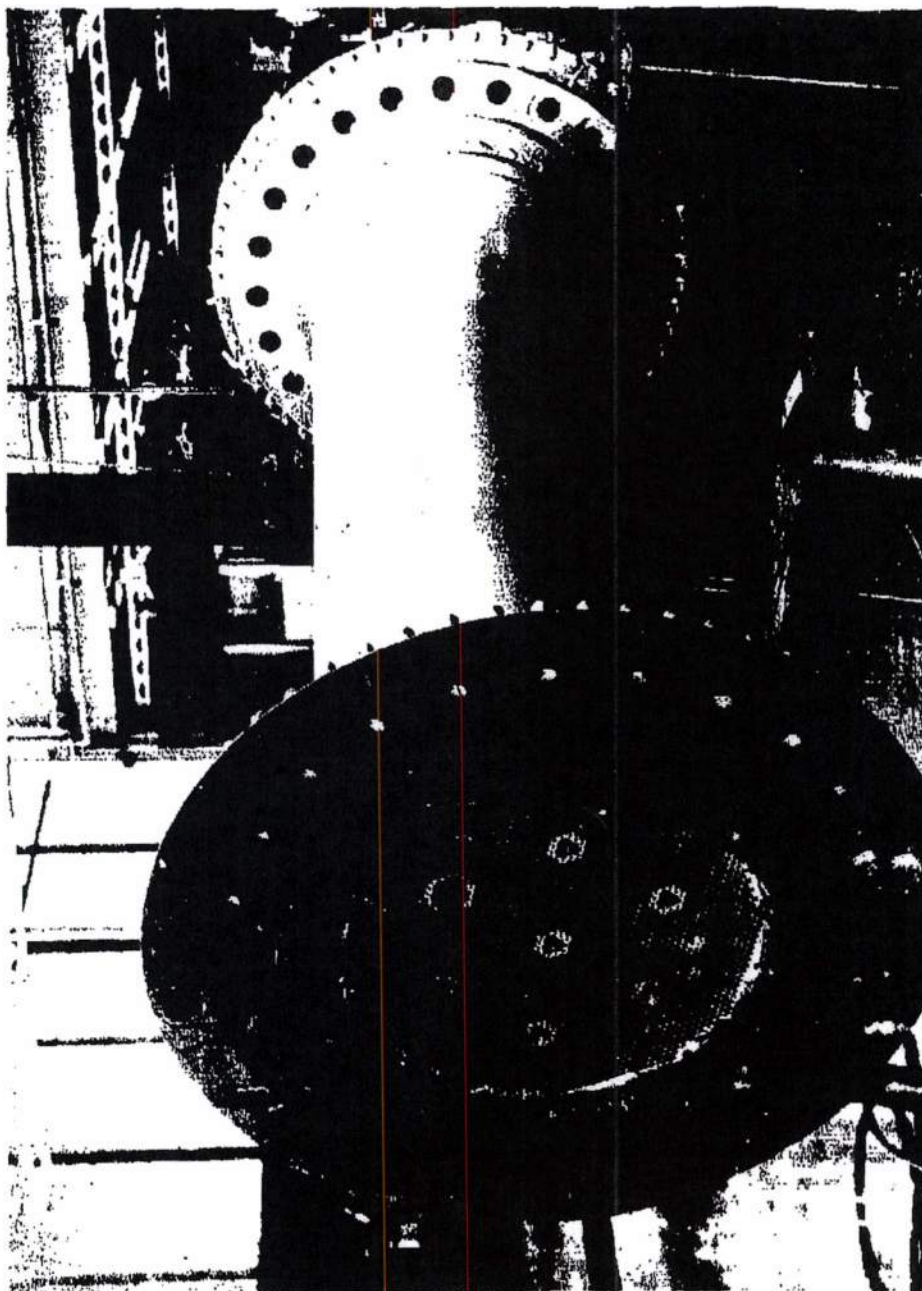


FIGURE 111 - Simulated Reactor Segment Installed in 18-inch Duct

3946-9

~~CONFIDENTIAL~~



~~SECRET RESTRICTED DATA~~

REPORT 587

~~ATOMIC ENERGY ACT OF 1954~~

### Test Plan

The test plan was formulated on the basis of four test phases. In the first phase, the plan was to generate a pressure profile and to determine this profile at the face position of the reactor test section without the test section being installed.

In the second phase, the basic test section, with instrumentation, would be installed and tested with the same profiles. (The basic test section consists of the bundle of aluminum hexagonal tubes and the end retainer plates.) Test results from the first phase would be used to evaluate the validity of the analytically predicted pressure profile effects discussed earlier.

In the third test phase, the simulated fore and aft reactor support structures were to be added to the basic test section. However, between conceptual design and actual testing, it became evident that this configuration would be of secondary importance because of the changing Tory IIC fore and aft support design and the design of a flight type reactor. This phase was therefore dropped as an immediate test objective.

The final test phase was devoted to the investigation of reactor-nozzle coupling length. Three nozzle positions were evaluated with a flat pressure profile upstream of the test section.

All test runs were accomplished with a constant airflow of 70 pps at ambient temperature for full Reynolds number simulation at the tube exit and at a tube exit Mach number closely simulating actual reactor conditions.

The pressure instrumentation for the complete test item including measurement of total airflow, individual tube airflows, and duct pressure profile totaled about 150 individual pickups. Figure 112 shows schematically how some of this instrumentation was used to obtain tube Mach number, airflows, and pressure drops. Figure 113 shows the test item installed in the cell.

### Test Results

Only a gross analysis of the test data has been accomplished at this time to establish overall results and to determine the presence of any outstanding unexpected trends. A detailed discussion of the results, which will be compared to analytical predictions where possible, will be presented in the next progress report.

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

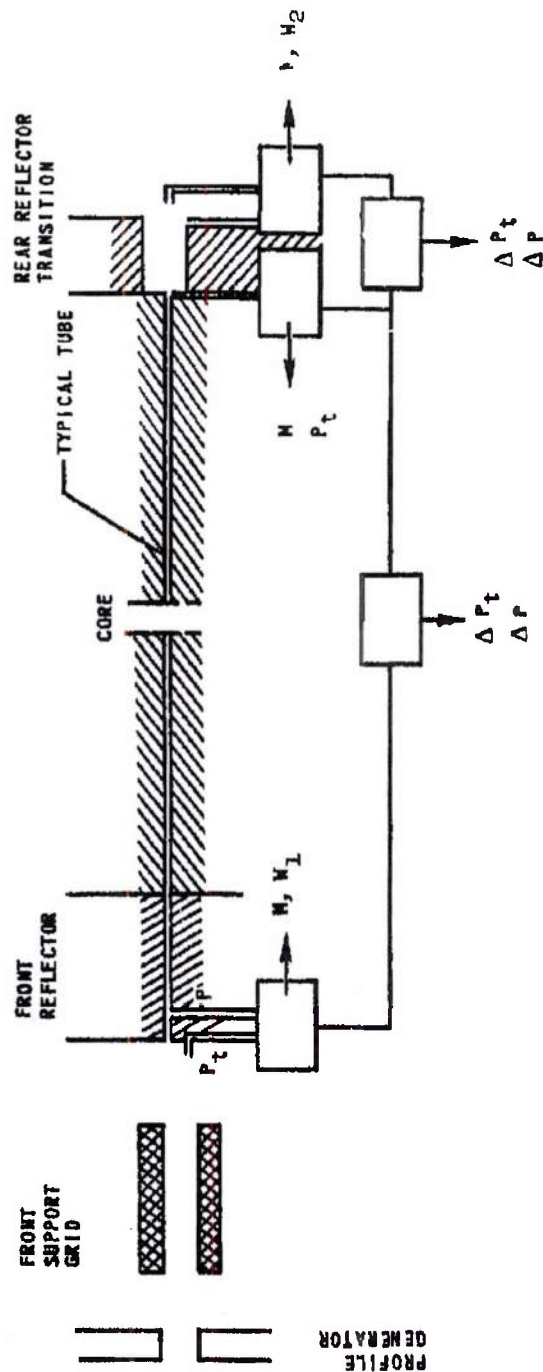
~~ATOMIC ENERGY ACT OF 1954~~

UNCLASSIFIED

The Marquardt Corporation  
VAN NUYS, CALIFORNIA

REP 5876

SCHEMATIC OF COUPLING TEST INSTRUMENTATION



$$ALSO \Delta p = f(M, W_L)$$

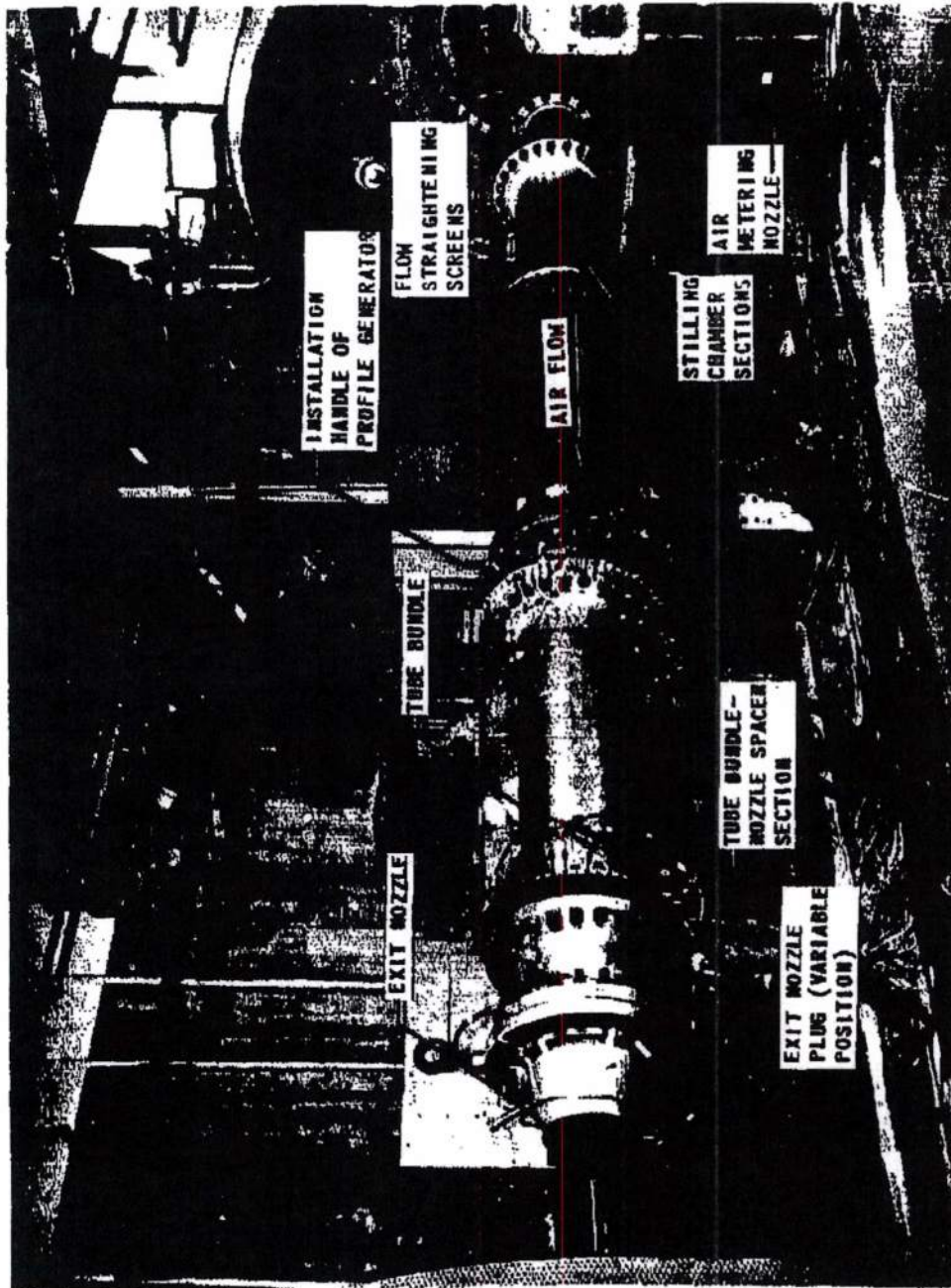
MAC 403



UNCLASSIFIED

*The Marquardt*  
VAN NUYS, CALIFORNIA

REPORT 58



T2972-3

MAC 153

UNCLASSIFIED

~~SECRET RESTRICTED DATA~~

MT 5876

~~ATOMIC ENERGY ACT OF 1954~~

Airflow distribution results, for imposed profiles and exit nozzle coupling length variation, are discussed below for the simulated fuel tube bundle (D<sub>e</sub> = 0.229 inches), which pass about 90 to 95 percent of the total air-flow.

### Imposed Profiles

Two types of total pressure profiles (in addition to the flat profile) were imposed at a distance of 14 inches (L/D<sub>R</sub> of 0.8) upstream of the tube bundle face by inserting unchoked concentric or eccentric orifices in the 18-inch ducting. Duct pressure distortions were measured about 2 inches downstream of the orifice (12 inches upstream of the tube bundle). The total pressure was again measured on the fore and aft faces of the tube bundle for a distance of tubes. The static pressure for the same tubes was measured just downstream of the tube entrance and again at the tube exit.

Two test points, Figures 114 and 115, are presented for the case of essentially flat profiles to be used later for comparing profiles and the effects of exit nozzle coupling length. Total pressure distortion in percent is indicated and is computed as:

$$\left( \frac{P_{T_{\max}} - P_{T_{\min}}}{P_{T_{\text{avg}}}} \right) \times 100$$

Using this method of computing distortion, the sign of the answer will always be positive.

For the detailed analysis to be presented in the next progress report, the following distortion parameters will be used:

$$\frac{P_{T_{\max}} - P_{T_{\text{avg}}}}{P_{T_{\text{avg}}}}, \frac{P_{T_{\min}} - P_{T_{\text{avg}}}}{P_{T_{\text{avg}}}}$$

However, this type of analysis requires manually computed, zone-weighted, pressure- and airflow-averaged numbers. Time was not available to accomplish this work.

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

MAC AGT

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

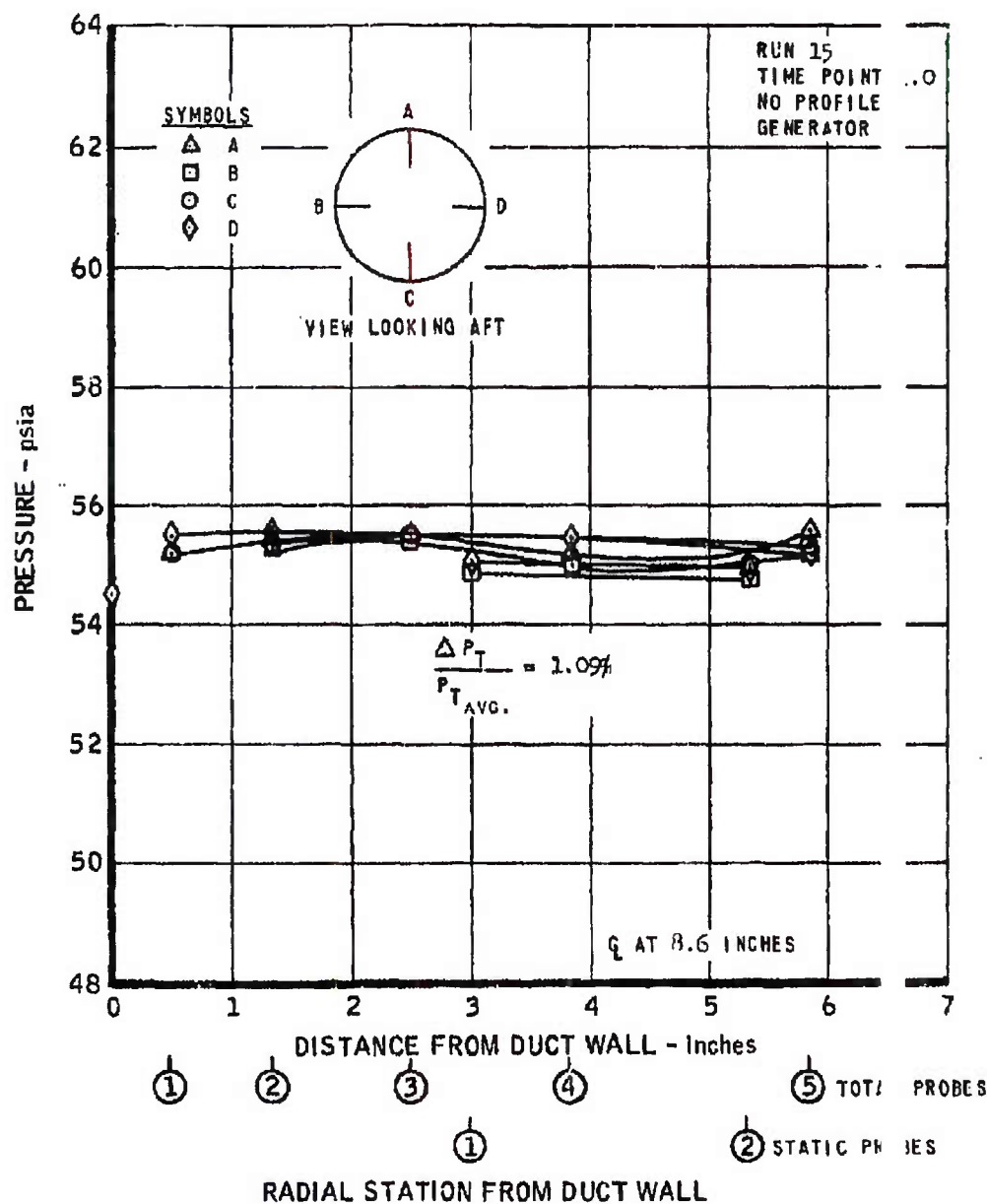
REPORT 58

~~CONFIDENTIAL~~

*Marquardt*  
 VAN NUYS, CALIFORNIA

5876

AERODYNAMIC COUPLING TEST  
 DUCT STATIC AND TOTAL PRESSURE PROFILES  
 MEASURED UPSTREAM FROM TUBE BUNDLE ENTRANCE



~~CONFIDENTIAL~~

22E619

-201-

FIGURE 115



~~SECRET RESTRICTED DATA~~

REPORT 58

ATOMIC ENERGY ACT OF 1954

Figures 116 and 117 show the total and static pressure distortion at the module exit for Figures 114 and 115. Primary tube airflow rate is also shown. Tube airflow distortion is presented and has been computed as:

$$\frac{W_{a_{\max}} - W_{a_{\min}}}{W_{a_{\text{avg}}}} \times 100$$

Figures 118 and 119 present the duct pressure profiles for concentric and eccentric profile generator orifices of the same size measured just downstream of the orifice plates. Although the same size, the eccentric profile generator (Figure 118) produces a higher distortion than does the concentric generator. Figures 120 and 121 present tube airflow and exit static distortion data, again measured at the tube bundle exit. Figure 122 presents the imposed duct profile generated by an orifice slightly smaller (but still unchoked) than that used for the previously discussed profiles. Figure 123 presents the corresponding tube bundle exit data. Figure 124 presents gross airflow distribution and aft face static pressure distortion data. The data indicate a variation of exit face static pressure profile with imposed total pressure profile. The variation of gross tube weight flow with imposed total pressure profile, while not completely analyzed at this time, is within 5 percent of the predicted value.

#### Exit Nozzle Coupling Length

Three exit nozzle coupling lengths were tested to determine whether the length of the nozzle coupling would impose a static pressure distortion on the aft face of the module exit. Length is defined as the distance between the aft face of the module and the start of the converging portion of the exit nozzle. Nozzle couplings of the following three lengths were tested:

- (1) A length thought sufficient to isolate any possible effects imposed by the nozzle. This was a length,  $L/D_R$ , of 1.34, where  $D_R = 17.25$  inches (the internal diameter of the module duct).
- (2) A length described as "design," which originated from the Mach 2.7 design point concept of the Model MA50-XA-1 full scale propulsion system. The "design" scaled length for the coupling test hardware was  $L/D_R = 0.335$ .

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WIS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

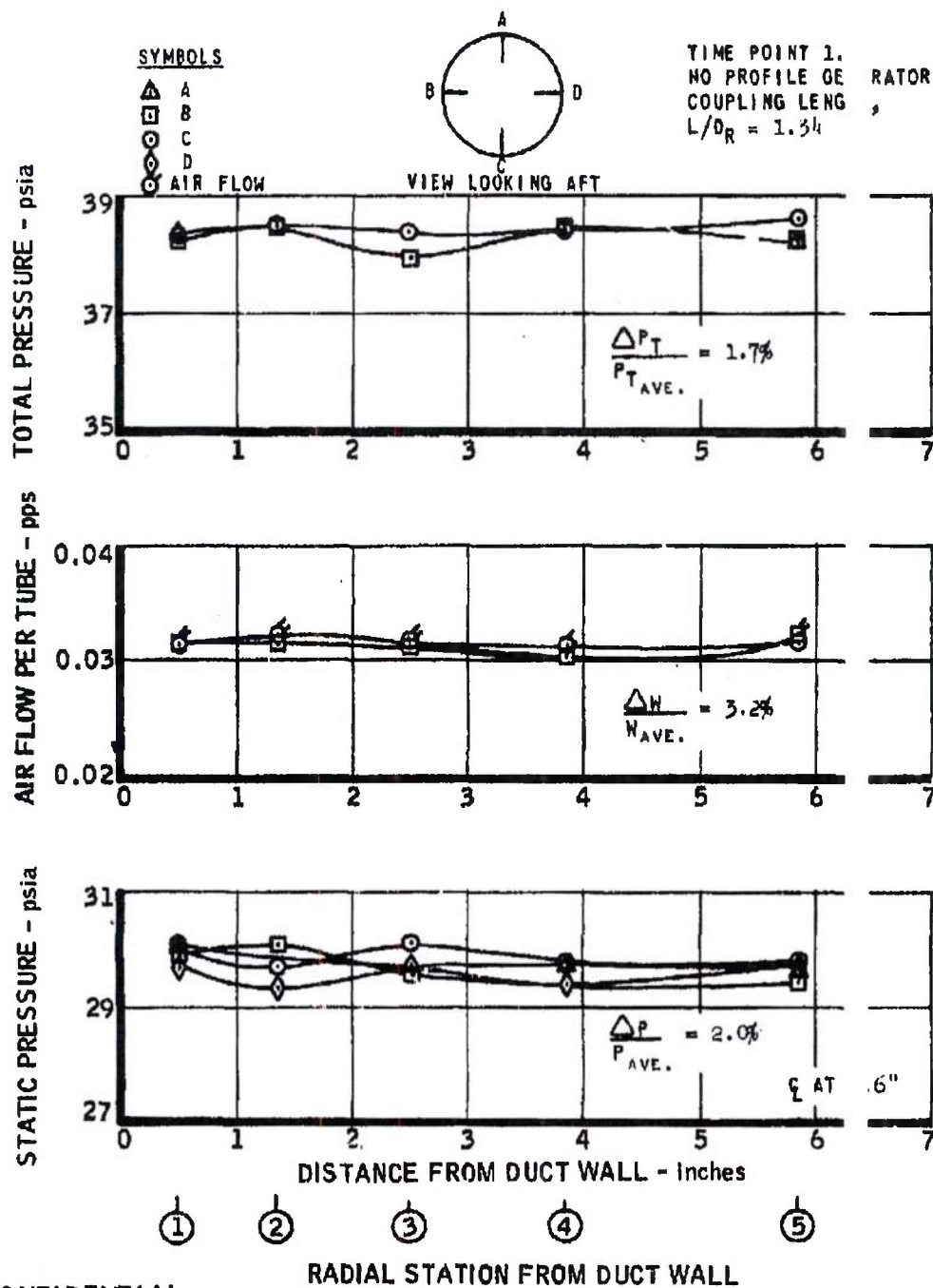
ATOMIC ENERGY ACT OF 1954

~~CONFIDENTIAL~~

*The Marquardt Company*  
VAN NUYS, CALIFORNIA

ORT 5876

# AIR FLOW AND PRESSURE DISTORTIONS MEASURED AT TUBE BUNDLE EXIT RIN 11



~~CONFIDENTIAL~~

22E620

-203-

FIGURE 116

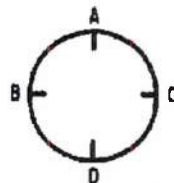
DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~CONFIDENTIAL~~

# AIR FLOW AND PRESSURE DISTORTIONS MEASURED AT TUBE BUNDLE EXIT RUN 15

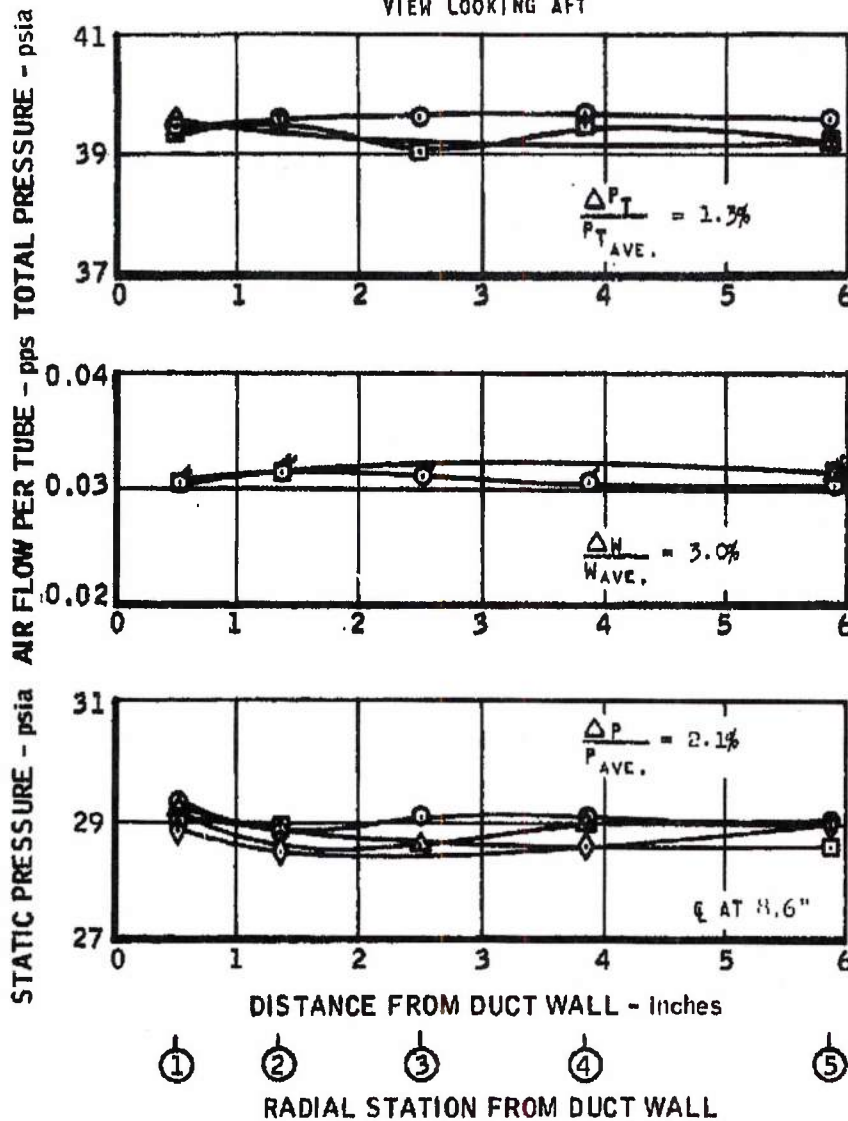
## SYMBOLS

- △ A
- B
- C
- ◇ D
- ⊙ AIR FLOW



TIME POINT 1.0  
 NO PROFILE GENERATOR  
 COUPLING LENGTH,  
 $L/D_R = 1.34$

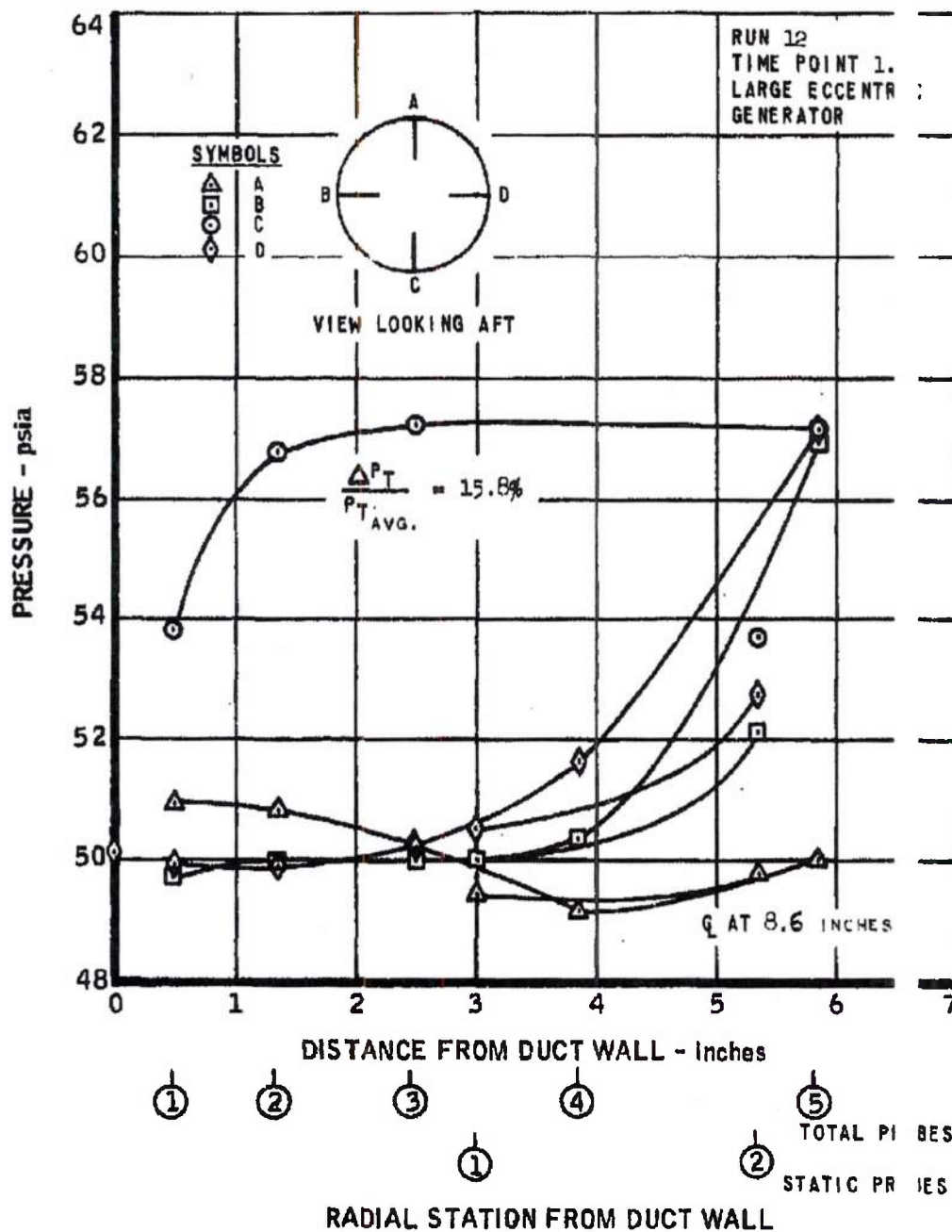
VIEW LOOKING AFT



~~CONFIDENTIAL~~

~~CONFIDENTIAL~~

# AERODYNAMIC COUPLING TEST DUCT STATIC AND TOTAL PRESSURE PROFILES MEASURED UPSTREAM FROM TUBE BUNDLE ENTRANCE

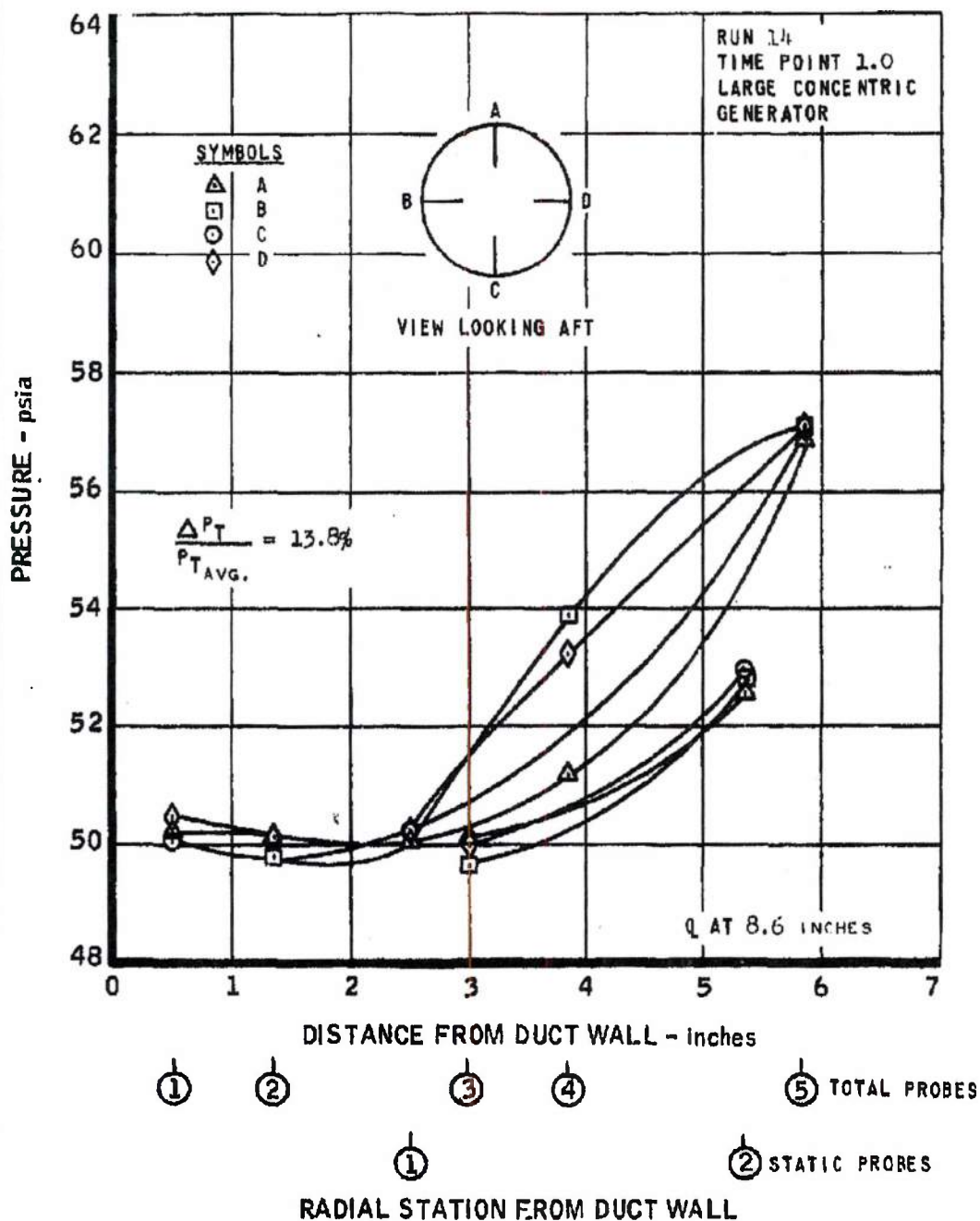


~~CONFIDENTIAL~~



~~CONFIDENTIAL~~

AERODYNAMIC COUPLING TEST  
 DUCT STATIC AND TOTAL PRESSURE PROFILES  
 MEASURED UPSTREAM FROM TUBE BUNDLE ENTRANCE



~~CONFIDENTIAL~~

~~CONFIDENTIAL~~

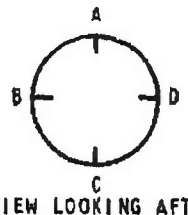
*The Marquardt*  
 CORPORATION  
 VAN NUYS, CALIFORNIA

PORT 5876

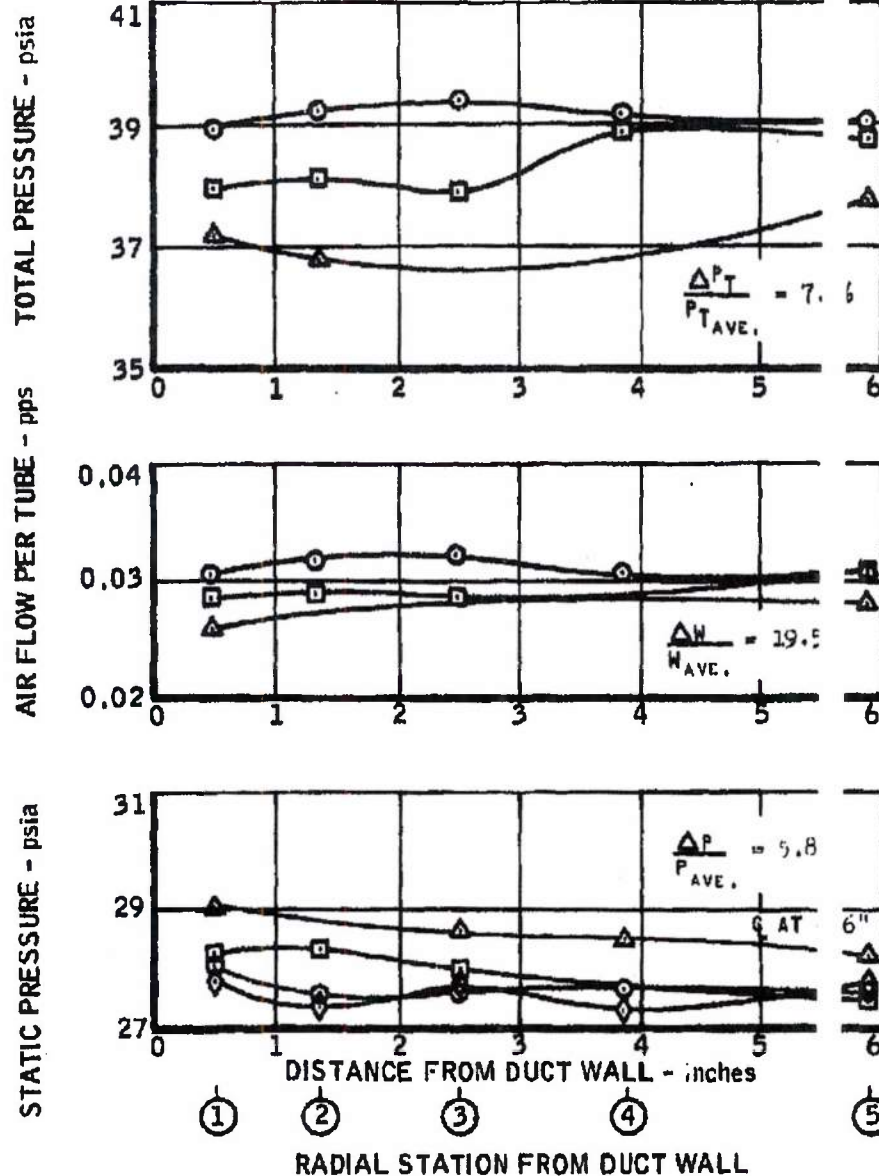
# AIR FLOW AND PRESSURE DISTORTIONS MEASURED AT TURBINE EXIT RUN 12

## SYMBOLS

- △ A
- B
- C
- ◇ D
- ⊙ AIR FLOW



TIME POINT 1.  
 LARGE ECCENTRICITY  
 GENERATOR



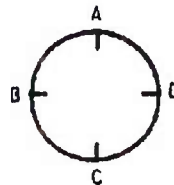
~~CONFIDENTIAL~~

~~CONFIDENTIAL~~

# AIR FLOW AND PRESSURE DISTORTIONS MEASURED AT TURBINE BUNDLE EXIT RUN 14

## SYMBOLS

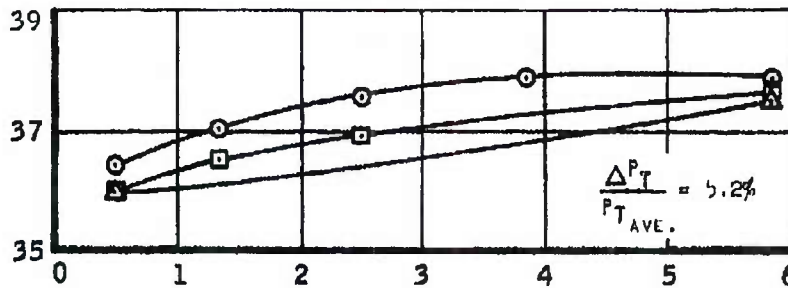
- △ A
- B
- C
- ◇ D
- AIR FLOW



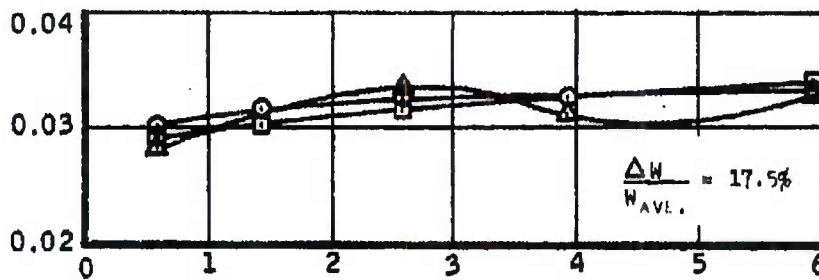
TIME POINT 1.0  
 LARGE CONCENTRIC GENERATOR

VIEW LOOKING AFT

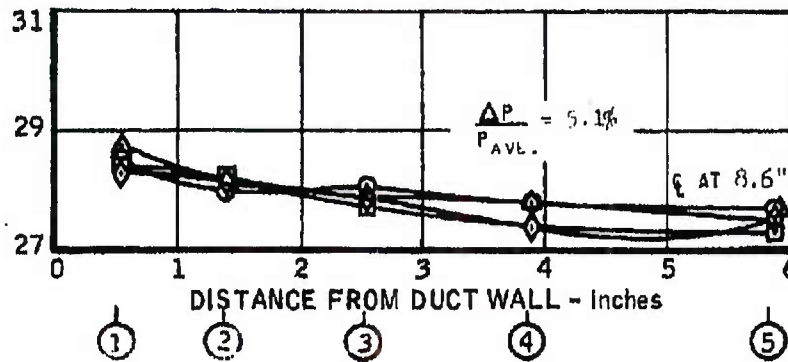
TOTAL PRESSURE - psia



AIR FLOW PER TUBE - pps



STATIC PRESSURE - psia



DISTANCE FROM DUCT WALL - Inches

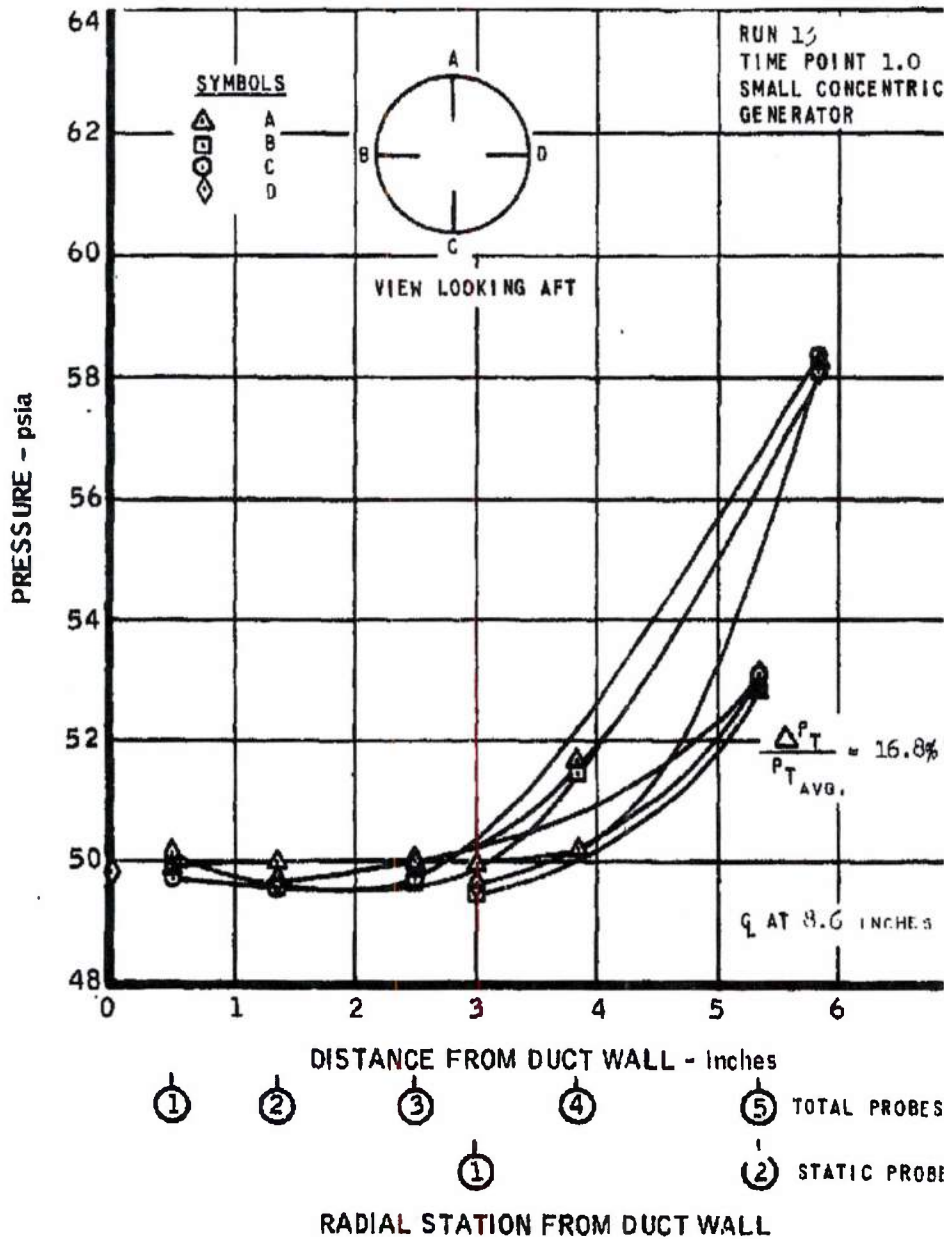
RADIAL STATION FROM DUCT WALL

① ② ③ ④ ⑤

~~CONFIDENTIAL~~

~~CONFIDENTIAL~~

AERODYNAMIC COUPLING TEST  
 DUCT STATIC AND TOTAL PRESSURE PROFILES  
 MEASURED UPSTREAM FROM TUBE BUNDLE ENTRANCE

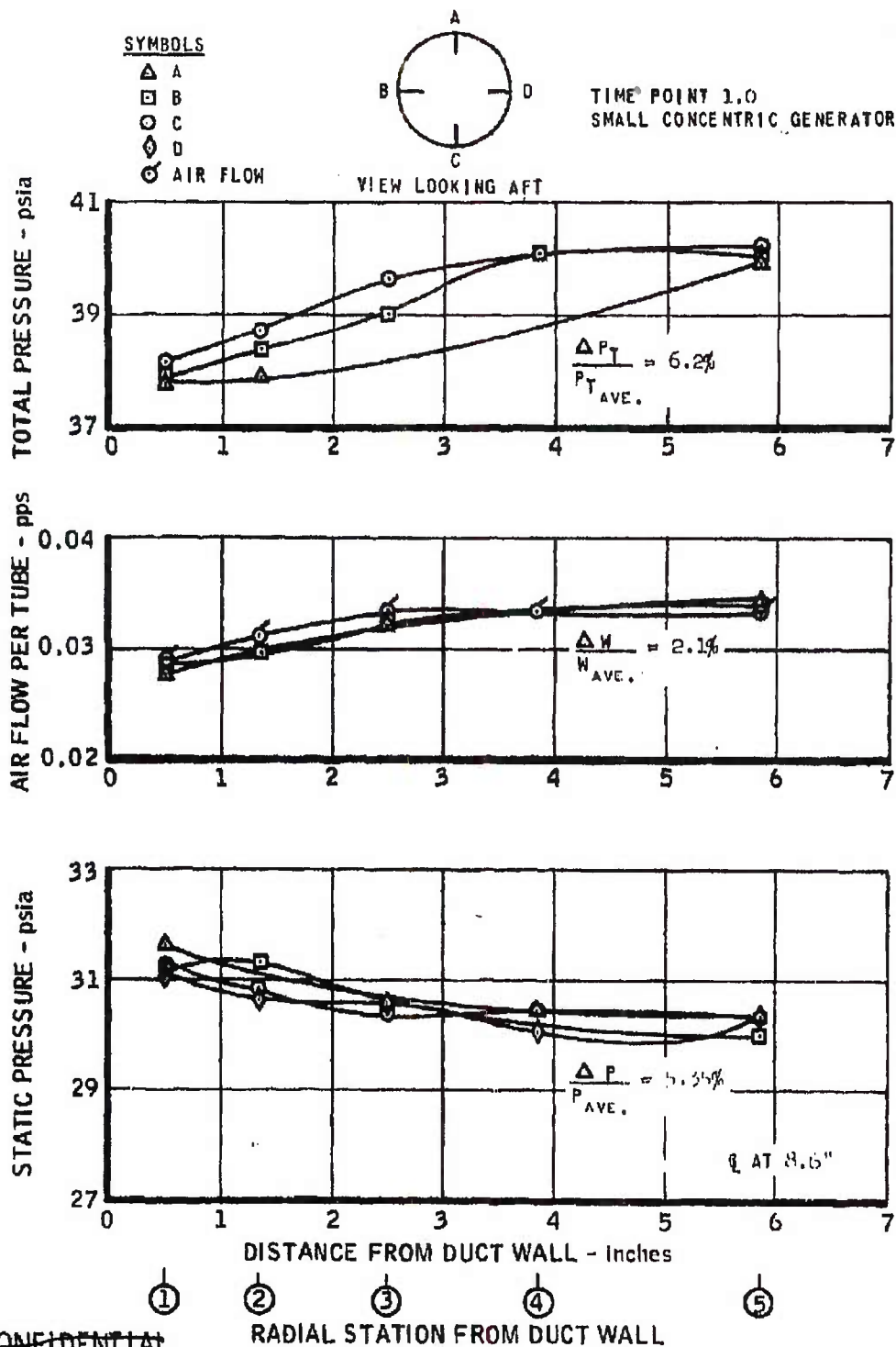


~~CONFIDENTIAL~~



CONFIDENTIAL

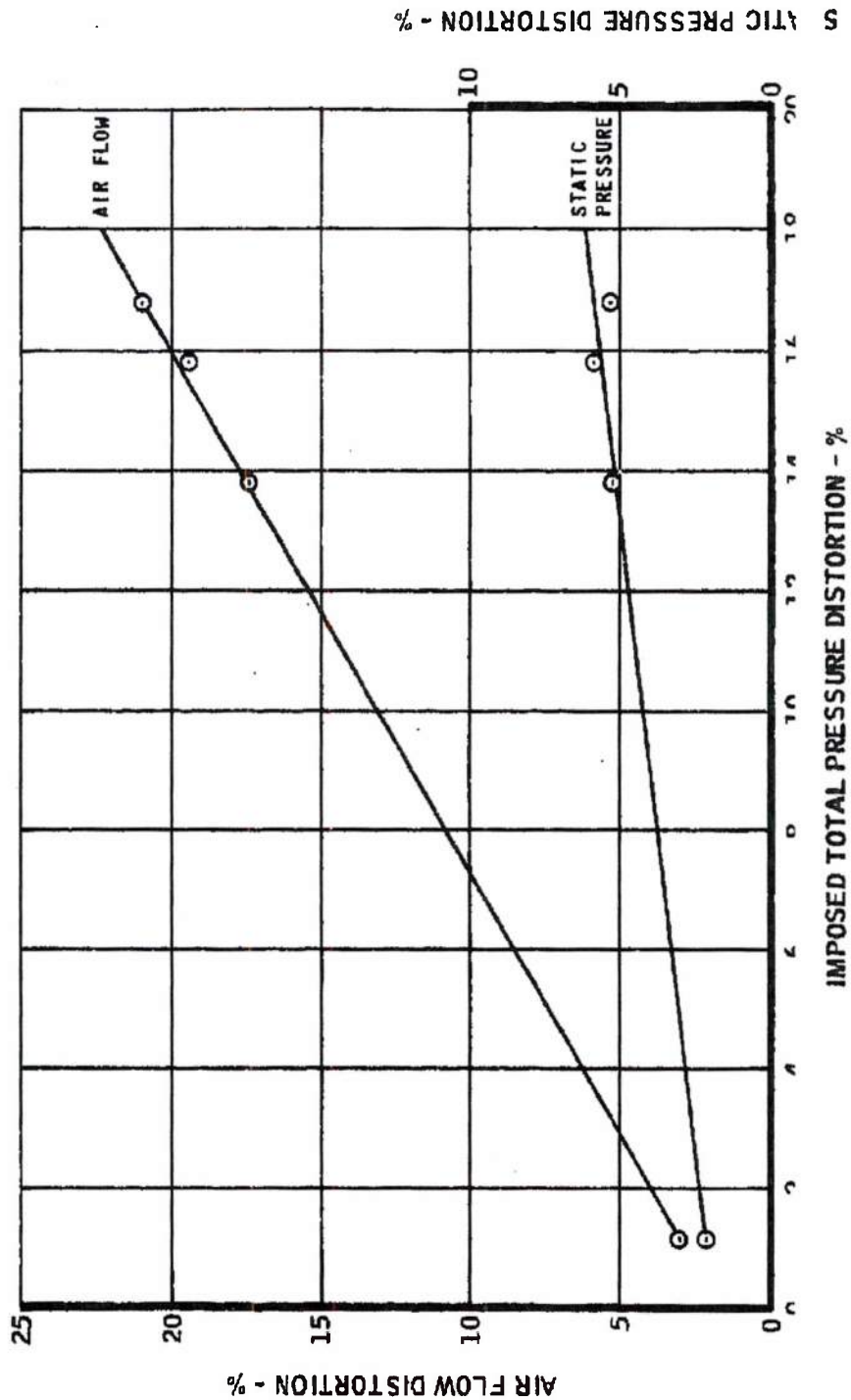
# AIR FLOW AND PRESSURE DISTORTIONS MEASURED AT TUBE BUNDLE EXI RUN 13



CONFIDENTIAL

~~CONFIDENTIAL~~

IMPOSED PRESSURE PROFILE DISTORTION ANALYSIS



MAC 403

~~CONFIDENTIAL~~

22E628

~~SECRET RESTRICTED DATA~~

REPORT 58 5

ATOMIC ENERGY ACT OF 1954

- (3) A minimum length consistent with instrumentation lead-in and physical attachment of the nozzle to the module exit station. This length was  $L/D_R = 0.25$ .

All test runs to evaluate length effects were made without imposing module inlet pressure profiles. Inlet total pressure distortion for all runs is about 1.1 percent.

Figures 125 and 126 present the airflow and pressure distortion data for the "design" and minimum length, while Figures 116 and 117 present the data for the long length ( $L/D_R = 1.34$ ). Using the static pressure and airflow distortion data for the three coupling lengths, inspection of Figure 127 indicates that the "design" coupling length would have to be increased from  $L/D_R = 0.335$  to approximately  $L/D_R = 0.41$  to reduce the distortion level to the "base" case of the long length. The actual distortion data for the "base" case are used here only in a qualitative manner, because the data presented is subject to more detailed analysis. However, applying this qualitative data to the full scale Model MA50-XCA propulsion system indicates that the upstream plenum chamber for the full scale nozzle will have to be increased in length by 5 to inches.

#### Noise and Vibration Analysis

Noise (pressure level) and vibration data were recorded for all of the test runs. In addition, data were recorded during several test runs for conditions with the exit nozzle plug-in, which results in a lower tube exit Mach number. Data recorded in this manner should aid in defining the effect of the exit velocity on sound level. It is anticipated that noise and vibration data obtained from the aerodynamic coupling test will give insight into the noise levels of a full scale propulsion system employing this type of nuclear reactor as the heat source.

The recorded noise and vibration data have not been analyzed at this time. However, Figure 128 presents a sample of the raw data. These data indicate that no discrete frequencies occur and that only random noise levels are present.

#### 3.8.4 Nozzle Attachment Test

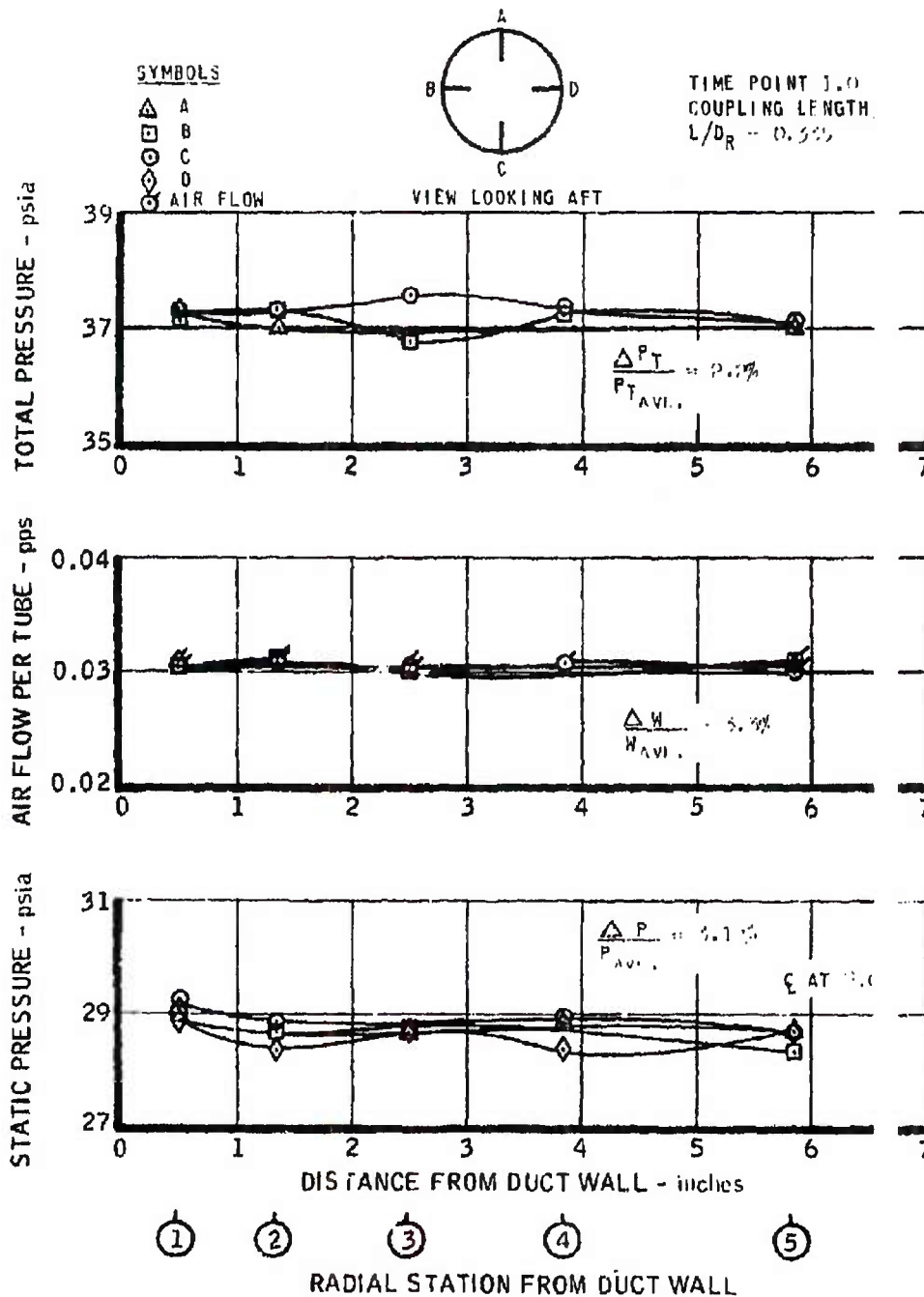
A study has been made to investigate airflow leakage results of the nozzle attachment test to determine what the effect would be on overall propulsion system thrust.

~~SECRET RESTRICTED DATA~~

ATOMIC ENERGY ACT OF 1954

~~CONFIDENTIAL~~

AIR FLOW AND PRESSURE DISTORTION DATA FOR DESIGN COUPLING LENGTH  
 RUN 17



MAC A 65

~~CONFIDENTIAL~~

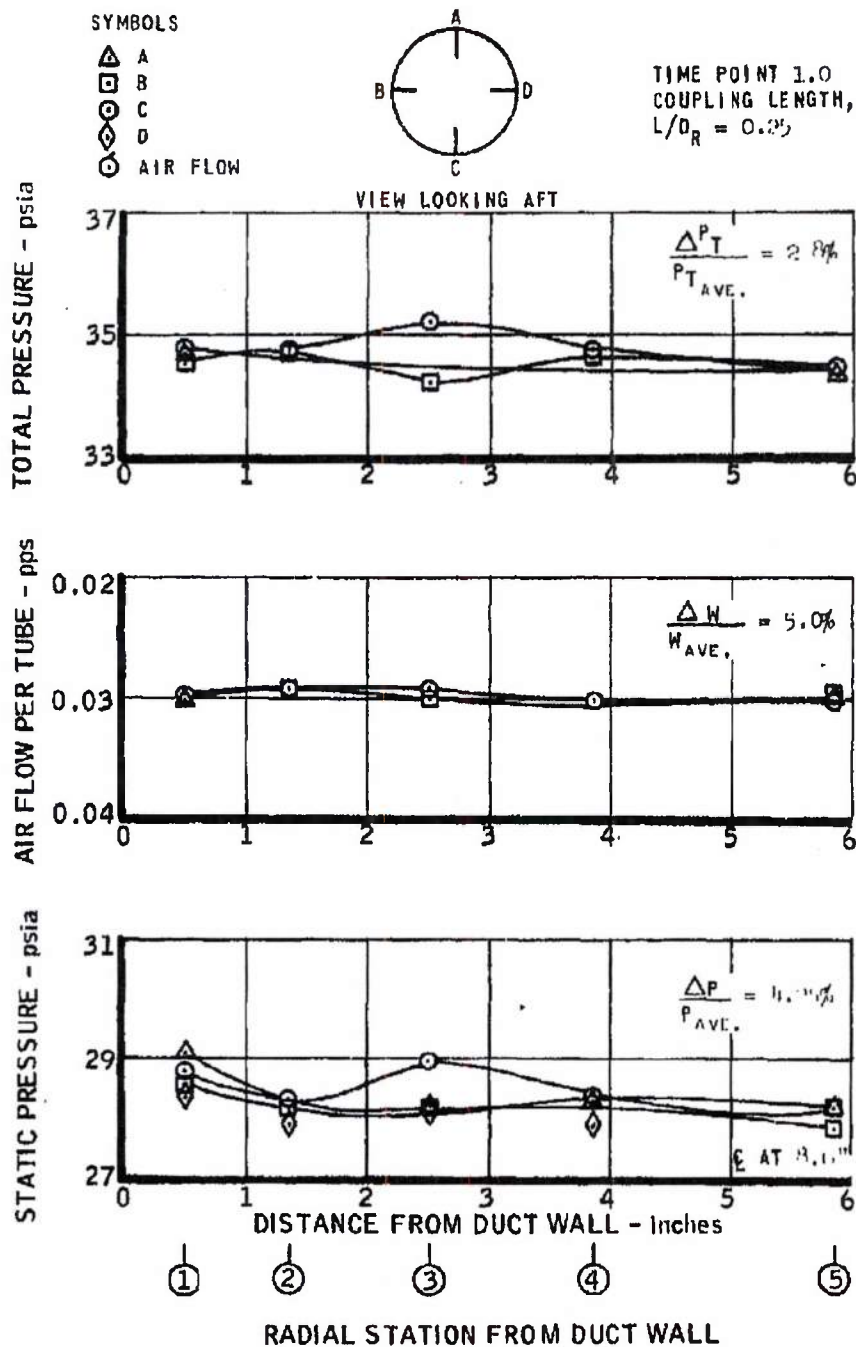


CONFIDENTIAL

THE *Marquardt* CORPORATION  
 VAN NUYS, CALIFORNIA

REPORT 587

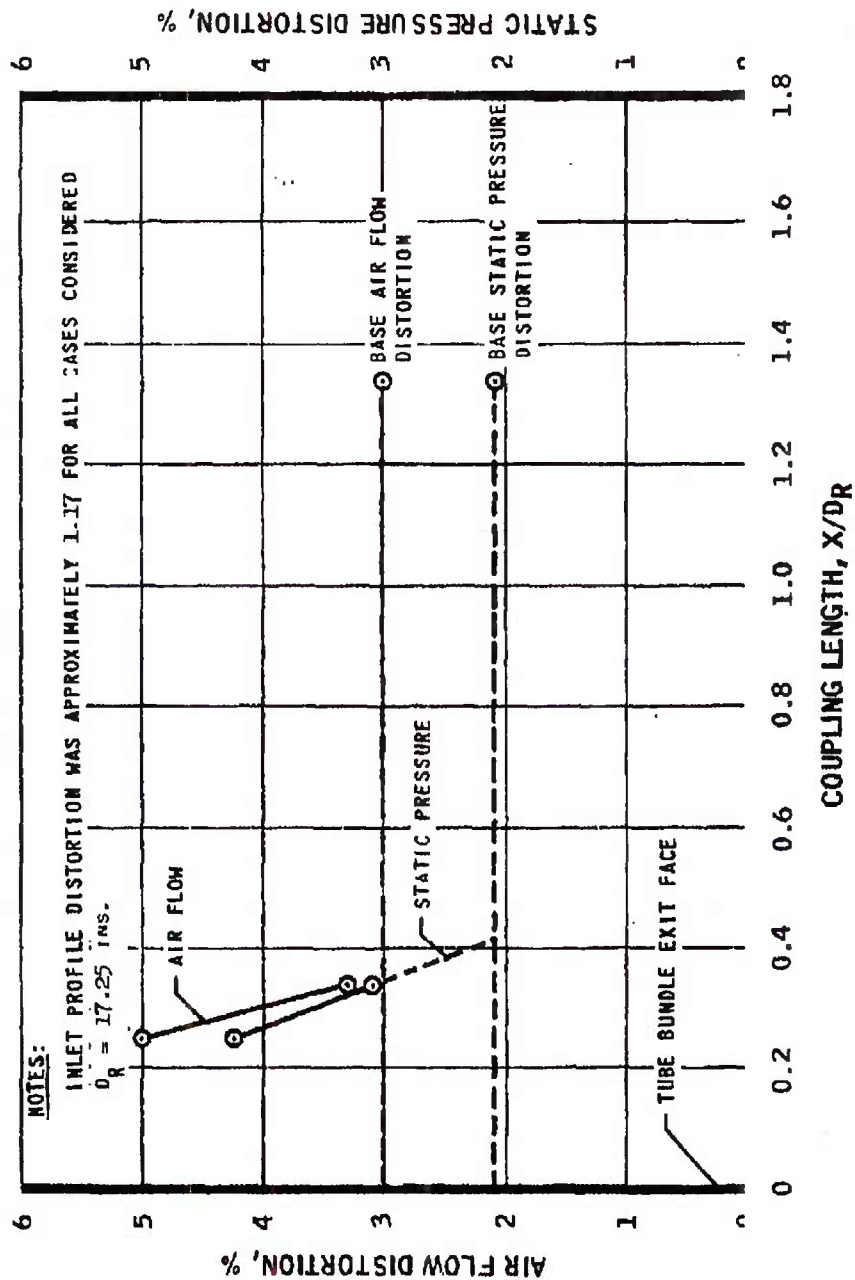
# AIR FLOW AND PRESSURE DISTORTION DATA FOR MINIMUM COUPLING LENGTH RUN 16



CONFIDENTIAL

CONFIDENTIAL

# EFFECT OF COUPLING LENGTH ON DISTORTION



MAC AGO

CONFIDENTIAL

22E631

-215-

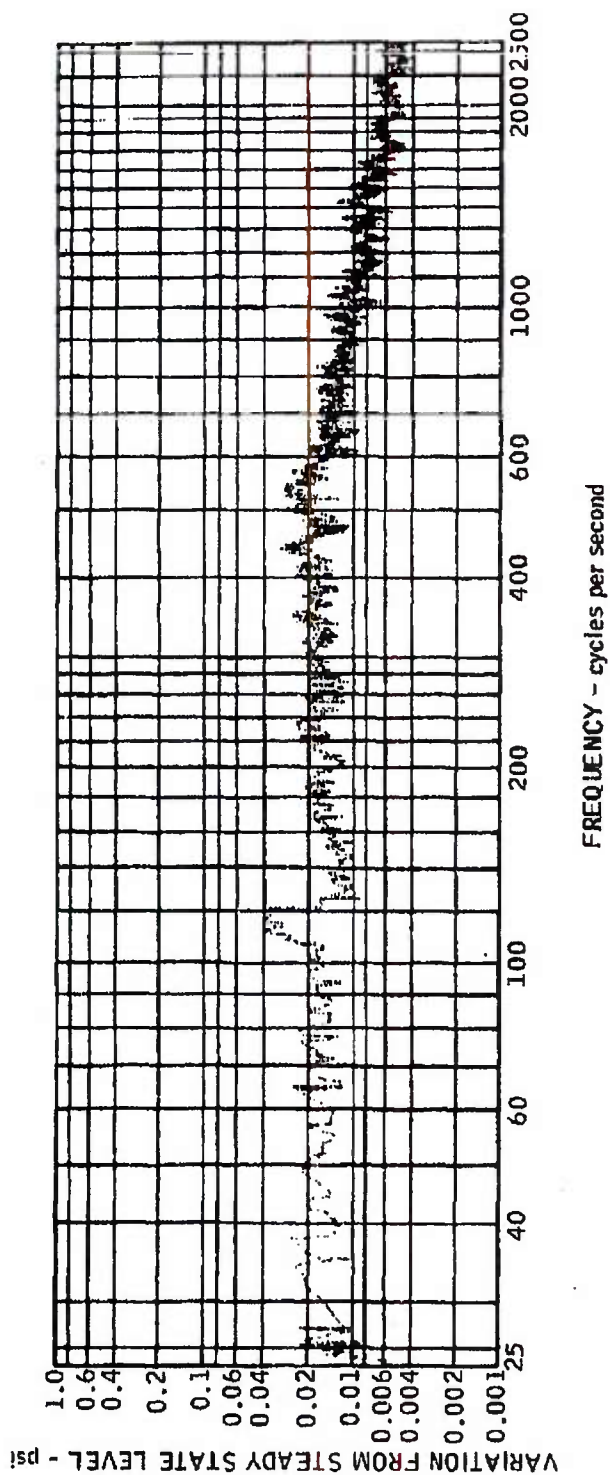
FIGURE 127

*The Marquardt*  
CORPORATION  
VAN NUYS, CALIFORNIA

REPORT 5876

UNCLASSIFIED

RECORDED NOISE AND VIBRATION DATA



NOTES:

RAW DATA FROM COUPLING TEST, RUN 15  
(TUBE BUNDLE INSTALLED, NO IMPOSED PROFILE)

TRANSDUCER

PHOTOCON

LOCATION

AFT

DIRECTION

BANDWIDTH .PS

UNCLASSIFIED



POST 5876

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

Taking the leakage rate reported at the ambient temperature conditions from Section 3.9.6, an effective choked flow area can be computed. Assuming this flow area, a change in air temperature and a constant pressure, a curve of airflow rate versus temperature can be computed. Figure 129 presents such a curve with the additional data point obtained from the test at high temperatures. While the latter data point indicates that the effective leakage area decreases with temperature, the following analyses will assume the conservative computed curve results.

At the Model MA50-XCA engine design point condition (Mach 2.8, an altitude of 1000 feet, ANA Hot Day), the temperature of the Model MA50-XCA side support-exit nozzle cooling air in the vicinity of the nozzle attachment ring is about 1050°F. The static pressure will be approximately 250 psig. Assuming that the attachment ring is at this air temperature (conservative result will be obtained because the temperature of the ring will be slightly higher than the cooling air temperature), a leakage rate of 0.41 pps is indicated from the curve. The reactor total airflow rate at design point is 1577 pps. Thus, the leakage rate is about 0.03 percent. The Model MA50-XA-1 thrust influence coefficients are applicable to the Model MA50-XCA engine to the first order. From these coefficients, the leakage rate represents a thrust decrement of 0.1 percent, which is considered negligible.

### 3.9 STRUCTURAL EXPERIMENTS

#### 3.9.1 Exhaust Nozzle Attachment Test

The purpose of the exhaust nozzle attachment test was to evaluate the operational reliability and structural integrity of a full scale nozzle attachment assembly under simulated load and temperature conditions. The attachment method chosen for investigation was a threaded coupling arrangement in which an internally threaded locking ring engaged external threads on the mating nozzle section. A labyrinth-type seal was used to close off the joint. Details of the attachment are shown in Figure 56. All components were fabricated from A-286 material.

The mated rings were fitted to a specially designed bellows fixture, which closed off the ends of the test item, allowing it to be internally pressurized. This arrangement can be seen in Figure 130.

Because of the potential hazard associated with the use of air as a pressurizing medium, special safety precautions were exercised. Refrasil was

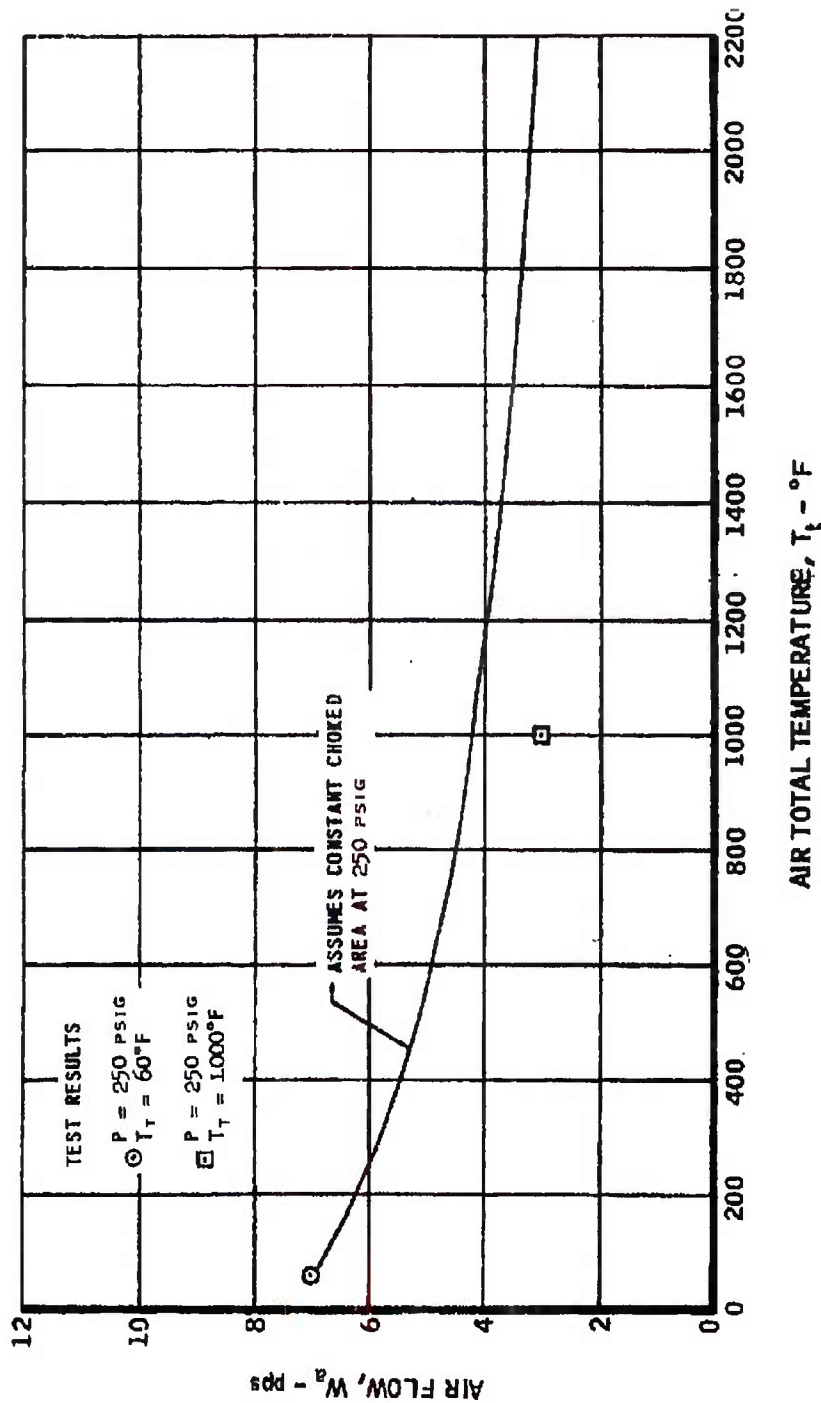
~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~



UNCLASSIFIED

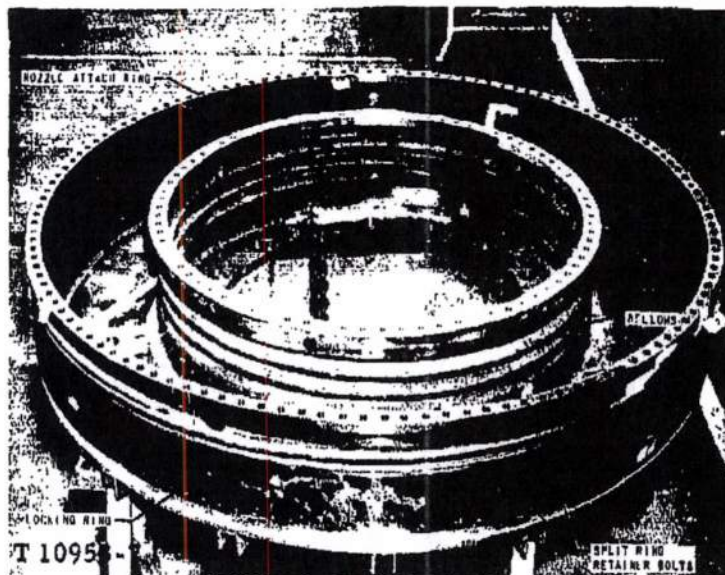
AIR FLOW LEAKAGE RESULTS OF NOZZLE ATTACHMENT TEST



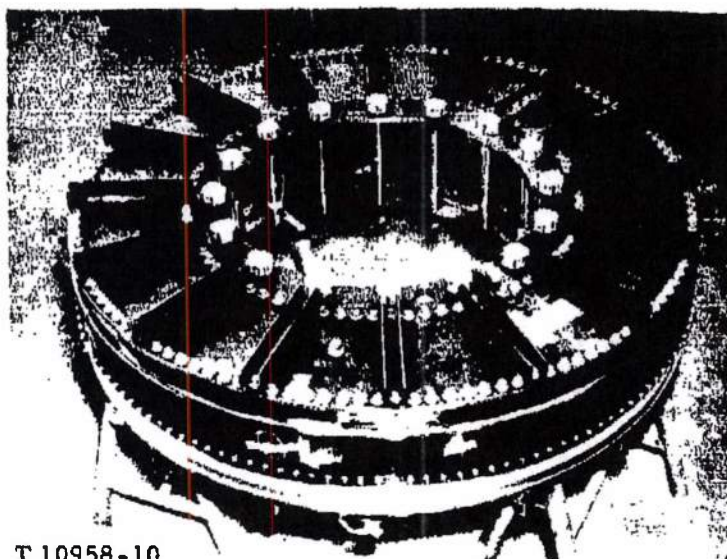
MAC A63

UNCLASSIFIED

UNCLASSIFIED



A. Partial Assembly



B. Final Assembly

FIGURE 130 - Test Item for Exit Nozzle  
Attachment Test

MAC A&T

UNCLASSIFIED

~~SECRET RESTRICTED DATA~~

REPORT 5 26

~~ATOMIC ENERGY ACT OF 1954~~

packed into the annular chamber to reduce the volume of air, and a ring of large snubber bolts was installed to contain the hardware in the event of a structural failure.

Instrumentation included strain gages, thermocouples, and static pressure pickups. Figure 131 shows the test item being installed in a special prepared pit. Hot air was introduced into the pit from a SUE burner, providing temperatures up to 1400°F, and high-pressure air was used to impose an internal design load of 350,000 pounds.

Initial tests consisted of pressure checks at ambient temperature to record stresses and to measure air leakage through the aerodynamic seal. The test item was then disassembled and inspected. Ambient temperature tests were followed by a series of high-temperature, high-pressure tests. After each run, the test item was disassembled and checked for proper operation and dimensional change. In the final test run, the joint was held at design pressure and temperature (250 psig and 1400°F) for 3 1/2 hours, at which time the bellow fixture failed. Upon disassembly and inspection it was found that no dimensional change had occurred, and the locking ring still functioned properly. Results of the test can be summarized as follows:

- (1) Air leakage rates through the aerodynamic seal at ambient and 1100°F temperature were 0.69 pps and 0.29 pps, respectively, at 250 psig.
- (2) Adequate structural integrity of the joint was demonstrated.
- (3) Quick disconnect capability of the threaded lock ring was substantiated by the ease of ring operation after each test run.

### 3.9.2 Engine-Airframe Lateral Attachment Test

Late in the year an experiment was initiated to evaluate proposed engine airframe lateral attachment systems under simulated flight conditions of temperature and vibration. The test item will consist of a 10-inch thick full scale radial section of the reactor core and suspension system.

Primary test objectives include (1) the evaluation of assembly structural integrity, and (2) the determination of deformation modes, spring relaxation, and response to random and programmed vibrations.

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~



MAY 29 2015

THE *Marquardt*  
CORPORATION  
VAN NUYS, CALIFORNIA

UNCLASSIFIED

RT 5876

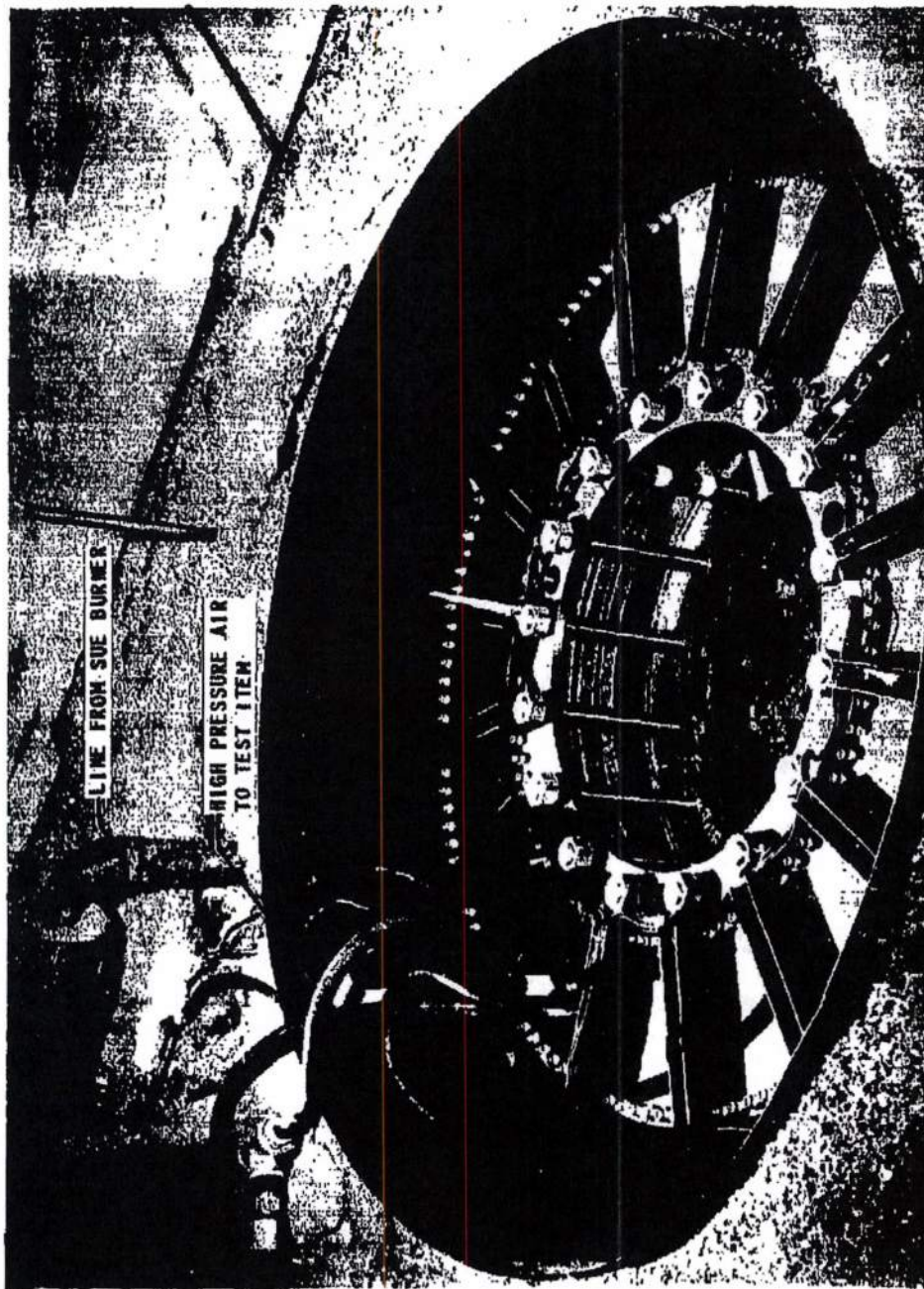


FIGURE 131 - Exit Nozzle Attachment Test Item in Ground Pit

T 10958-11

UNCLASSIFIED



~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

The first test, scheduled in February 1962, will involve a reactor support system utilizing corrugated springs, as shown in Figure 132. The simulated reactor core section will be built up of hexagonal stainless steel tubes. This section will allow simulation of mass and slip plane effects.

The test item will be mounted in a shaker table capable of imposing a 5-g sinusoidal vibration over a range of 5 to 2000 cps. Planned test conditions are listed in Table 14.

Calibration and checkout of facility control equipment and recording apparatus are complete; instrumentation for measuring acceleration, deflection, and strain have been installed on the test item; and the corrugated springs have been calibrated. Load-deflection characteristics of the springs are needed in order to impose the correct amount of preload on the core section, and to determine post-test spring relaxation.

A SUE burner will provide heated air for bringing the test item to the 1300° F design point temperature. The various components of the test hardware are shown in Figure 133.

### 3.10 MATERIALS INVESTIGATIONS

#### 3.10.1 High-Temperature Materials Data

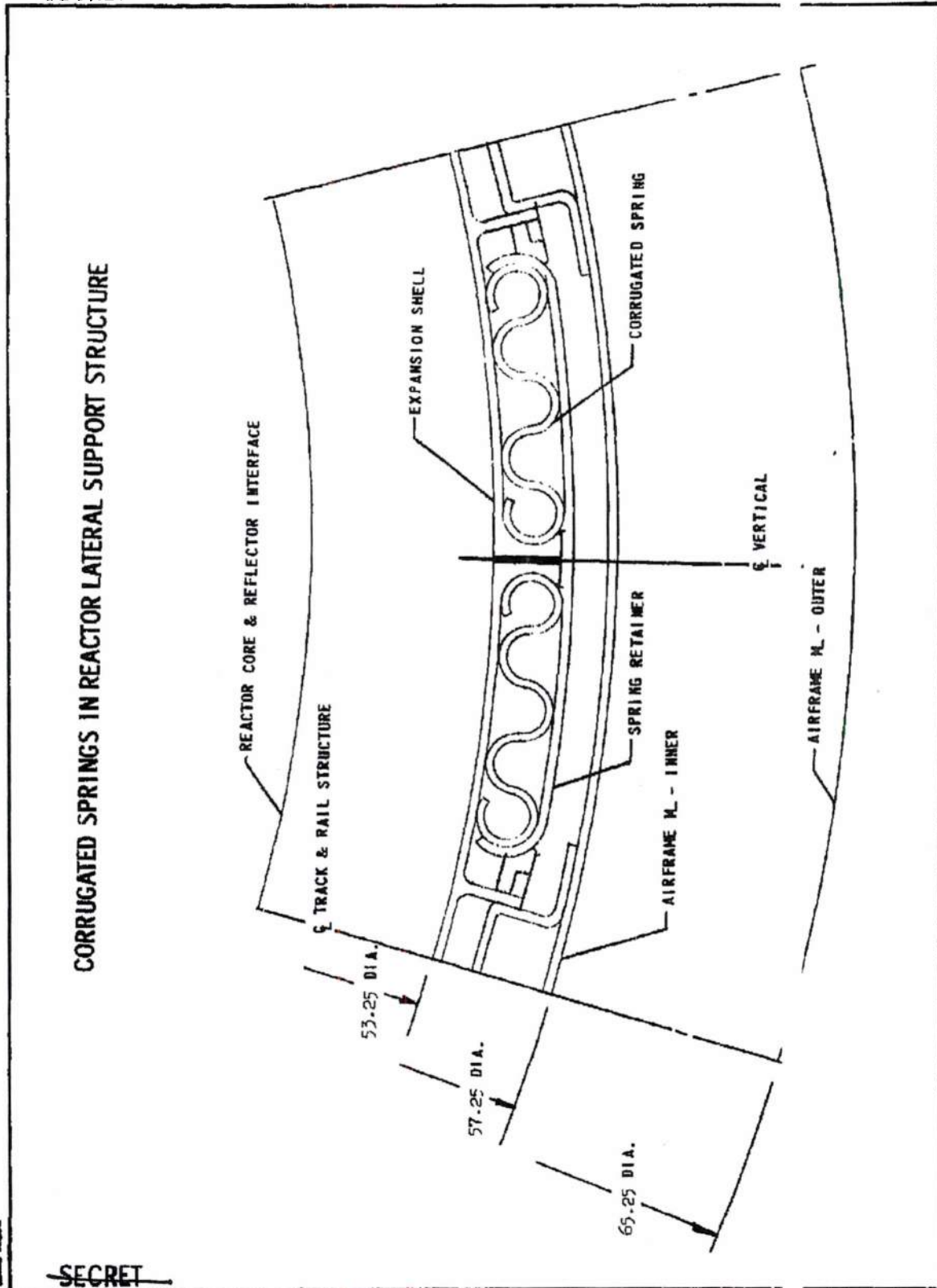
During the past year investigations have been conducted to obtain needed design information not presently available on alloys that have been chosen as candidate structural materials for the Pluto engine. The short time and/or creep rupture properties of base and welded material in tension have been studied for Hastelloy R-235 and Rene' 41 alloys, and, to a more limited extent, AISI type 321 stainless steel. Similar properties of base material for the Inco 713C and Hastelloy C alloys were studied. The tests performed on Hastelloy C are part of a program to study the comparative properties of base and welded air- and vacuum-melted material.

The tensile properties were studied in a temperature range from 1800° F as applicable to each alloy. The creep deformations of interest were between 0.1 and 1.0 percent, and the times for creep and rupture were between 0 minutes and 10 hours. The alloys were in the form of sheet, plate, or cast rod; welds were performed by the TIG (tungsten electrode, inert gas) process. The data summarized here (Tables 15 through 27 and Figures 134 through 138) give the results obtained, in a comparative manner, for the base and welded materials of Hastelloy R-235 alloy and Rene' 41 alloy sheet and plate, AISI type 321 stainless steel sheet, and the base material of Hastelloy C air-melted alloy plate and Inco 713C alloy cast rods.

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

~~SECRET~~



MAC 4632

~~SECRET~~

N22L5

-223-

FIGURE 132

SECRET RESTRICTED DATA

THE *Marquardt* Corporation  
VAN NUYS, CALIFORNIA

REPORT 5 16

~~ATOMIC ENERGY ACT OF 1954~~

TABLE 14

TEST CONDITIONS FOR VIBRATION  
OF SIMULATED REACTOR CORE SECTION

	Cond. No.	Temp. (° F)	Frequency (cps)	Input	Input	Duration (min)	Number of Tests
Assembly	1	Room	NA	--	--	--	--
Static*	2	Room	NA	--	--	--	--
Frequency Scans	3	Room	5 - 1000	0.5	NA	15	2
	4	Room	5 - 1000	1.0	NA	15	2
	5	Room	5 - 1000	1.5	NA	15	2
Static	6	Room	NA	--	--	--	--
Flat Random	7	Room	5 - 2000	1.95 rms	0.002	15	1
	8	Room	5 - 2000	1.95 rms	0.002	15	1
	9	Room	5 - 2000	3.2 rms	0.005	15	1
Static	10	Room	NA	--	--	--	--
Flat Random	11	1300	5 - 2000	1.95 rms	0.002	15	1
	12	1300	5 - 2000	1.95 rms	0.002	15	1
	13	1300	5 - 2000	3.2 rms	0.005	15	1
Static	14	Room	NA	--	--	--	--
Programmed Random	15	1300	5 - 2000	(To be prescribed)		15	1
	16	1300	5 - 2000			10 hours	1
Static	17	Room	NA	--	--	--	1
Frequency Scan	18	Room	5 - 1000	0.5	NA	15	1

\* Static tests include core pressure measurement, spring preload measurement, and gaps between outer spring, shells and outer ring and between rails and mating tracks.

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

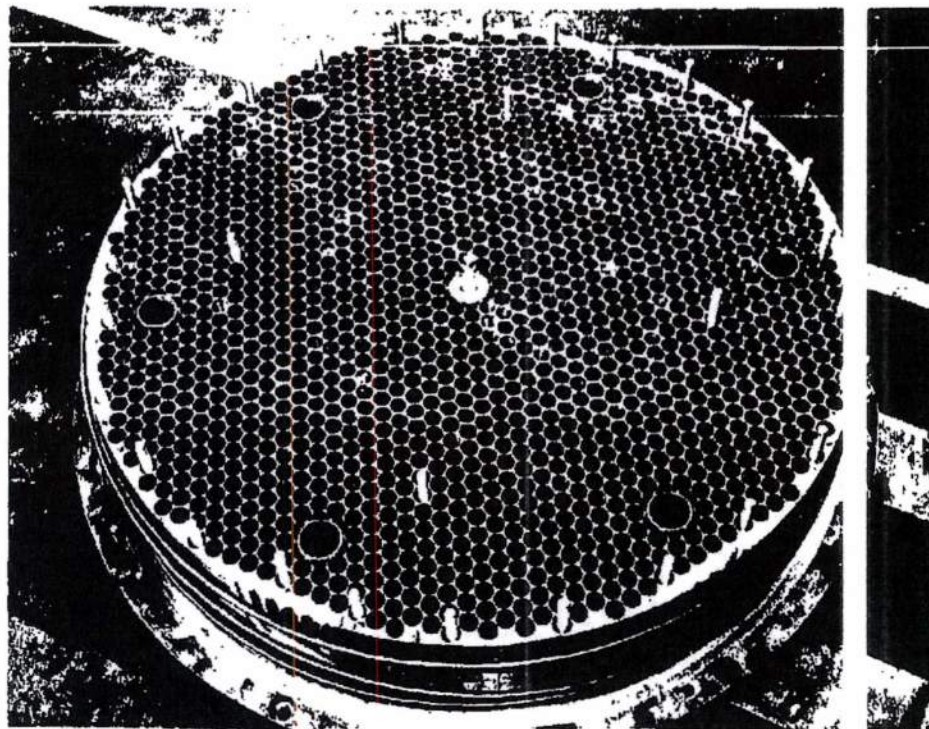
SECRET RESTRICTED DATA

~~ATOMIC ENERGY ACT OF 1954~~



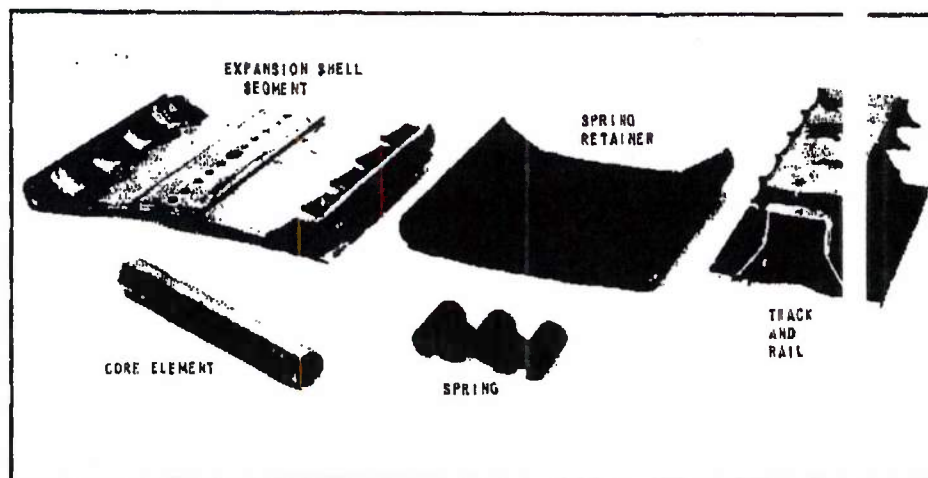
UNCLASSIFIED

PORT 5876



4142-7

A. Core Matrix



4142-8

B. Side Support Components

FIGURE 133 - Lateral Attachment Test Items

MAC 1430

UNCLASSIFIED



UNCLASSIFIED



REPORT 58

TABLE 15

COMPARATIVE SHORT TIME TENSILE PROPERTIES OF  
HASTELLOY R-235 ALLOY SHEET BASE AND WELDED MATERIAL

Test Temperature (° F)	Specimen Type*	Proportional Limit (Ksi)	0.2% Yield Strength (Ksi)	Ultimate Tensile Strength (Ksi)	Elongation in 2 in. (%)
78	B	89.0	103.0	167.0	27.5
	W	94.0	111.0	149.0	10.0
	WF	88.0	117.5	171.0	22.0
1200	B	88.0	97.0	140.0	30.0
	W	60.0	99.5	140.0	12.0
	WF	74.0	100.0	136.0	16.0
1400	B	94.0	107.0	133.0	7.5
	W	76.0	105.0	128.0	5.0
	WF	80.0	100.0	124.0	6.5
1600	B	63.0	88.0	98.0	2.5
	W	53.0	76.0	87.5	2.0
	WF	68.0	78.0	90.0	1.0
1800	B	26.0	30.0	40.7	15.0
	W	14.0	21.5	34.3	14.0
	WF	16.0	22.0	32.2	13.0

\* B = Base material: sheet 0.072 in. thick; aged at 1600° F for 30 minutes

W = Welded without filler by fusion; sheet 0.063 in. thick

WF = Welded with filler R-235 wire by fusion; sheet 0.063 in. thick

All welds transverse; aged at 1600° F for 30 minutes

Page determined to be Unclassified  
Reviewed Chief, RDD, WHS  
IAW EO 13526, Section 3.5  
Date: MAY 29 2015

UNCLASSIFIED

UNCLASSIFIED



5876

TABLE 16

COMPARATIVE CREEP AND RUPTURE PROPERTIES OF  
HASTELLOY R-235 ALLOY SHEET BASE AND WELDED MATERIAL

Test Temperature (°F)	Creep		Rupture Time (hours)	Stress (Ksi)	Material Tested*
	%	Time (hours)			
1200	0.1	0.5 min	48 min	110	B
	0.1	1.13	1.73	105	W
	0.1	2.7	2.7	95	WF
	0.5	44 min	--	110	B
	0.5	--	--	105	W
	0.5	--	--	95	WF
1400	0.1	18.4	18.4	50	B
	0.1	1.2	1.2	50	W
	0.1	0.27	0.27	50	WF
1600	0.1	16 min	20.5	25	B
	0.1	3.6 min	7.03	25	W
	0.1	26 min	39.5	25	WF
	0.5	10.33	--	25	B
	0.5	2.83	--	25	W
	0.5	13.7	--	25	WF
	1.0	15.83	--	25	B
	1.0	5.3	--	25	W
	1.0	27.5	--	25	WF
1800	0.1	40 min	Test Discont. 4.83	10	B
	0.1	1.25	9.9	9	W
	0.1	2.2	15.5	7	WF
	0.5	2.8	--	10	B
	0.5	4.16	--	9	W
	0.5	9.6	--	7	WF
	1.0	3.62	--	10	B
	1.0	5.8	--	9	W
	1.0	11.5	--	7	WF

\* B = Base metal; sheet 0.072 in. thick; aged at 1600° F for 30 minutes

W = Welded without filler; sheet 0.063 in. thick

WF = Welded with Hastelloy R-235 alloy filler wire; sheet 0.063 in. thick

All welds transverse; aged at 1600° F for 30 minutes

Page determined to be Unclassified  
Reviewed Chief, RDD, WHS  
IAW EO 13526, Section 3.5  
Date: MAY 29 2015

UNCLASSIFIED

UNCLASSIFIED

*Marquardt*  
CORPORATION  
VAN NUYS, CALIFORNIA

REPORT 587

TABLE 17

COMPARATIVE SHORT TIME TENSILE PROPERTIES OF  
HASTELLOY R-235 ALLOY PLATE BASE AND WELDED MATERIAL

Test Temperature (°F)	Specimen Type*	Proportional Limit (Ksi)	0.2% Yield Strength (Ksi)	Ultimate Tensile Strength (Ksi)	Young's Modulus (psi x 10 <sup>6</sup> )	Elongati in 2 in. (%)
78	B WF	70 --	94.2 --	156.3 ---	31.5 --	33 --
1200	B WF	60 59.0	84.3 82.0	106.0 121.0	26.0 23.4	24.5 18
1400	B WF	62 69.0	82.0 86.1	104.7 112.0	24.0 24.1	10 8
1600	B WF	54 60.4	72.9 75.2	83.0 93.0	21.0 19.3	9.5 6
1800	B WF	14 15.0	14.8 23.0	25.1 27.9	13.0 15.8	34.5 33

\* B = Base material: plate 0.250 in. thick; annealed at 2200° F for 15 minutes, water quenched; aged at 2050° F for 30 minutes, air cooled

WF = Welded with Hastelloy R-235 alloy filler wire; plate 0.250 in. thick

All welds transverse; annealed at 2200° F for 30 minutes, water quenched;  
aged 2050° F for 30 minutes, air cooled

Page determined to be unclassified  
Reviewed Chief, RDD, WHS  
IAW EO 13526, Section 3.5  
Date: MAY 29 2015

UNCLASSIFIED

UNCLASSIFIED

*Marquardt*  
CORPORATION  
VAN NUYS, CALIFORNIA

POST 5876

TABLE 16

COMPARATIVE CREEP AND RUPTURE PROPERTIES OF  
HASTELLOY R-235 ALLOY PLATE BASE AND WELDED MATERIAL

Test Temperature (°F)	Creep		Rupture Time (hours)	Stress (Ksi)	Material Tested*
	%	Time (hours)			
1200	0.1	7.13	7.2	85	F
	0.1	12.3	12.3	83	W
1400	0.1	17.0	Test discontinued	50	F
	0.1	4.65	4.67	50	W
1600	0.1	1.25	14.3	30	F
	0.1	0.33	5.07	30	W
	0.5	5.75	--	30	F
	0.5	2.15	--	30	W
	1.0	8.83	--	30	F
	1.0	3.33	--	30	W
1800	0.1	1.75	16.7	5	F
	0.1	1.6	32.0	5	W
	0.5	7.3	--	5	F
	0.5	10.7	--	5	W
	1.0	8.86	--	5	F
	1.0	32.0	--	5	W

\* B = Base metal; plate 0.250 in. thick; annealed at 2200° F for 15 minutes, water quenched; aged at 2050° F for 30 minutes, air cooled

WF = Welded with Hastelloy R-235 filler wire; plate 0.250 in. thick

All welds transverse; annealed at 2200° F for 15 minutes, water quenched; aged at 2050° F for 30 minutes, air cooled

Page determined to be Unclassified  
Reviewed Ghet, RDD, WHS  
IAW EO 13526, Section 3.5  
Date: MAY 29 2015

MAC 457

UNCLASSIFIED



UNCLASSIFIED

*The Marguardt Corporation*  
VAN NUYS, CALIFORNIA

REPORT 5 76

TABLE 19

COMPARATIVE SHORT TIME TENSILE PROPERTIES OF  
RENE' 41 ALLOY SHEET BASE AND WELDED MATERIAL

Test Temperature (° F)	Specimen Type*	Proportional Limit (Ksi)	0.2% Yield Strength (Ksi)	Ultimate Tensile Strength (Ksi)	Elongation in 2 in. (%)
78	B	75	102.2	148.4	13
	W	64.6	93.6	148.0	27
	WF	81.0	104.0	136.0	6.5
1200	B	58.4	89.8	134.2	23
	W	44.0	80.0	119.5	27
	WF	70.0	88.5	122.0	29
1400	B	56.4	90.9	139.6	17
	W	70.0	88.0	109.0	8
	WF	74.5	93.0	114.0	4
1600	B	52.8	81.9	97.2	9.5
	W	51.0	78.0	97.2	7.5
	WF	67.5	80.0	93.0	3.0
1800	B	30.7	38.6	44.8	15
	W	26.0	32.8	43.9	16
	WF	24.5	36.0	43.4	12

\* B = Base material: sheet 0.064 in. thick; annealed at 2150° F for 2 hrs, air cooled; aged at 1650° F for 2 hrs, air cooled

W = Welded without filler; sheet 0.053 in. thick

WF = Welded with Rene' 41 alloy wire

All welds transverse; annealed at 2150° F for 2 hrs, air cooled; aged at 1650° F for 4 hrs, air cooled

Page determined to be Unclassified  
Reviewed Ghiet, RDD, WHS  
IAW EO 13526, Section 3.5  
Date: MAY 29 2015

UNCLASSIFIED

UNCLASSIFIED



SEP 1 5876

TABLE 20

COMPARATIVE CREEP AND RUPTURE PROPERTIES OF  
RENE' 41 ALLOY SHEET BASE AND WELDED MATERIAL

Test Temperature (° F)	Creep		Rupture Time (hours)	Stress (Ksi)	Material Tested*
	%	Time (hours)			
1200	0.1	0.26	43.1	100	B
	0.05	21	86.8	100	W
1400	0.1	20.3	65	60	B
	0.2	8.8	22.2	65	W
	0.5	14.5	--	65	W
	0.6	48.9	--	60	B
	1.0	60	--	60	B
	1.0	20	--	65	W
1600	0.1	28.7	12.6	35	B
	0.05	3.5	26.3	32	W
	0.5	8.1	--	35	B
	0.5	15.9	--	32	W
	1.0	9.8	--	35	B
	1.0	22	--	32	W
1800	0.1	4.1	28.6	10	B
	0.05	0.33	50.7	11	W
	0.5	12.7	--	10	B
	0.5	4.2	--	11	W
	1.0	18.3	--	10	B
	1.0	49	--	11	W

\* B = Base material: sheet 0.064 in. thick; annealed at 2150° F for 2 hrs, air cooled; aged at 1650° F for 4 hrs, air cooled

W = Welded without filler; sheet 0.050 in. thick

All welds transverse; annealed at 2150° F for 2 hrs, air cooled; aged at 1650° F for 4 hrs, air cooled

Page determined to be Unclassified  
Reviewed Chief, RDD, WHS  
IAW EO 13526, Section 3.5  
Date: MAY 29 2015

MAC 103

UNCLASSIFIED

-231-

UNCLASSIFIED

*The Marquardt*  
 COMPANY  
 VAN NUTS, CALIFORNIA

REPORT 587

TABLE 21

COMPARATIVE SHORT TIME TENSILE PROPERTIES OF  
 RENE' 41 ALLOY PLATE BASE AND WELDED MATERIAL

Test Temperature (° F)	Specimen Type*	Proportional Limit (Ksi)	0.2% Yield Strength (Ksi)	Ultimate Tensile Strength (Ksi)	Young's Modulus (psi x 10 <sup>6</sup> )	Elongation in 2 in. (%)
78	B	94	110	138	30	4.5
	WF	84.9	113	168	28.9	13.5
1200	B	73	96	+	24+	+
	WF	72	97.5	138	24.2	8.0
1400	B	76	102	151	21	10.5
	WF	68	87.9	142	21.9	8.0
1600	B	65	88	100	19	14.5
	WF	75	94.2	108	20.7	8.5
1800	B	27	29	39	17.5	22
	WF	29.5	38.7	47.9	16.9	5.0

\* B = Base material: 5/16 in. plate; annealed at 2150° F for 2 hrs, air cooled; aged at 1650° F for 4 hrs, air cooled

W = Welded with filler Rene' 41 wire; 0.250 in. plate

All welds transverse; annealed at 2150° F for 2 hrs, air cooled; aged at 1650° F for 4 hrs, air cooled

+ = Grips failed prior to ultimate loading

Page determined to be unclassified  
 Reviewed Ghet, RDD, WHS  
 IAW EO 13526, Section 3.5  
 Date: MAY 29 2015

UNCLASSIFIED

-232-

MAC 403

UNCLASSIFIED



RE NT 5876

TABLE 22

COMPARATIVE CREEP AND RUPTURE PROPERTIES OF  
RENE' 41 ALLOY PLATE BASE AND WELDED MATERIAL

Test Temperature (°F)	Creep		Rupture Time (hours)	Stress (Ksi)	Material Tested*
	%	Time (hours)			
1200	0.1	1.0 min	Test discontinued	120	B
	0.1	32.5	Test discontinued	95	F
	0.5	3.23	--	120	B
	0.5	113.0	--	95	F
	1.0	12.75	--	120	B
	1.0	--	--	95	F
1400	0.1	3.0	17.5	75	B
	0.1	1.0	10.6	76	F
	0.5	8.86	--	75	B
	0.5	3.67	--	76	F
	1.0	11.9	--	75	B
	1.0	5.55	--	76	F
1600	0.1	3.6	16.2	35	B
	0.1	1.5	7.5	34	F
	0.5	10.9	--	35	B
	0.5	4.1	--	34	F
	1.0	12.7	--	35	B
	1.0	5.13	--	34	F
1800	0.1	2.75	7.95	10	B
	0.1	1.0	6.1	12	F
	0.5	5.2	--	10	B
	0.5	2.57	--	12	F
	1.0	5.95	--	10	B
	1.0	3.5	--	12	F

\* B = Base material; plate 0.3125 in. thick; annealed at 2150° F for 2 hrs, air cooled; aged at 1650° F for 4 hrs, air cooled

WF = Welded with filler Rene' 41 wire; 0.250 in. plate

All welds transverse; annealed at 2150° F for 2 hrs, air cooled; aged at 1650° F for 4 hrs, air cooled

Page determined to be Unclassified  
Reviewed Chief, RDD, WHS  
IAW EO 13526, Section 3.5  
Date: MAY 29 2015

MAC 167

UNCLASSIFIED



UNCLASSIFIED

THE *Marquardt*  
CORPORATION  
VAN NUYS, CALIFORNIA

REPORT 58

TABLE 23

COMPARATIVE SHORT TIME TENSILE PROPERTIES OF  
AISI TYPE 321 STAINLESS STEEL SHEET, BASE, AND WELDED MATERIAL

Test Temperature (° F)	Specimen Type*	Proportional Limit (Ksi)	0.2% Yield Strength (Ksi)	Ultimate Tensile Strength (Ksi)	Young's Modulus (psi x 10 <sup>6</sup> )	Elongatic in 2 in. (%)
72	B	26	43	83	25	55
	W	30	43	84	25	47
300	B	23	37	66	22	37
	W	28	38	66	20	37
600	B	26	34	60	17	33
	W	29	34	60	19	29
800	B	26	36	59	21	31
	W	23	32	57	24	27

\* B = Base material; sheet 0.125 in. thick

W = Welded material without filler; sheet 0.125 in. thick

All welds transverse; roll planished after welding

Page determined to be Unclassified  
Reviewed Chiet, RDD, WHS  
IAW EO 13526, Section 3.5  
Date: MAY 29 2015

UNCLASSIFIED

-234-

BAC 4673

UNCLASSIFIED

THE *Marquardt*  
CORPORATION  
VAN NUYS, CALIFORNIA

DPT 5876

TABLE 24

## SHORT TIME TENSILE PROPERTIES OF INCO 713 ALLOY

Test Temperature (°F)	Proportional Limit (Ksi)	0.2% Yield Strength (Ksi)	Ultimate Tensile Strength (Ksi)	Young's Modulus (psi x 10 <sup>6</sup> )	Elongation 1/2 in. (%)
78	86	115	132	27.2	5.5
1200	80	104	128	26	4
1400	89	108	128	25	2
1600	84	110.5	119	18	3
1800	34	51	74	14	6.5

Material: as cast rods 0.250 in. diameter

Heat treatment: as received

Page determined to be Unclassified  
Reviewed Chiet, RDD, WHS  
IAW EO 13526, Section 3.5  
Date:

MAY 29 2015

UNCLASSIFIED

UNCLASSIFIED

THE  
*Marquardt*  
CORPORATION  
VAN NUYS, CALIFORNIA

REPORT 58

TABLE 25

## CREEP AND RUPTURE PROPERTIES OF INCO 713C ALLOY

Test Temperature (° F)	Creep		Rupture Time (hours)	Stress (Ksi)
	%	Time (hours)		
1200	0.1	4.25	No rupture	110
	0.5	13.9	--	110
1400	0.1	0.28	21.2	80
	0.5	3.1	--	80
	1.0	7.5	--	80
1600	0.1	0.25	17.4	45
	0.5	3.5	--	45
	1.0	8	--	45
1800	0.1	0.5 min	3.46	30
	0.5	0.3	--	30
	1.0	2.03	--	30

Material: as cast rods 0.250 in. diameter

Heat Treatment: as received

Page determined to be Unclassified  
Reviewed Chief, RDD, WHS  
IAW EO 13526, Section 3.5  
Date: MAY 29 2015

UNCLASSIFIED

-236-

MAC 4673

UNCLASSIFIED

THE  
*Marquardt*  
CORPORATION  
VAN NUYS, CALIFORNIA

REP 5876

TABLE 26

SHORT TIME TENSILE TEST PROPERTIES OF  
HASTELLOY C ALLOY PLATE - AIR MELTED

Test Temperature (°F)	Proportional Limit (Ksi)	0.2% Yield Strength (Ksi)	Ultimate Tensile Strength (Ksi)	Elongation in 2 in. (%)
78	30.0	57.5	115.6	58
1000	27.5	37.3	92.3	53
1200	26.8	37.0	85.2	53
1400	27.0	33.3	67.9	44
1600	28.0	32.2	55.3	43

Material: plate 0.250 in. thick

Heat Treatment: as received from mill

Page determined to be unclassified  
Reviewed Grist, RDD, WHS  
IAW EO 13526, Section 3.5  
Date: MAY 29 2015

MAC A03

UNCLASSIFIED



TABLE 27

CREEP AND RUPTURE PROPERTIES OF  
HASTELLOY C ALLOY PLATE - AIR MELTED

Test Temperature (° F)	Creep		Rupture Time (minutes)	Stress (Ksi)
	%	Time (minutes)		
1200	0.1	9.0	Not ruptured	40
	0.5	39.2	--	40
	1.0	46.9	--	40
1400	0.1	0.13	Not ruptured	30
	0.5	1.17	--	30
	1.0	1.82	--	30
1600	0.1	0.02	2.20	20
	0.5	0.10	--	20
	1.0	0.17	--	20

Material: plate 0.250 in. thick

Heat Treatment: as received from mill

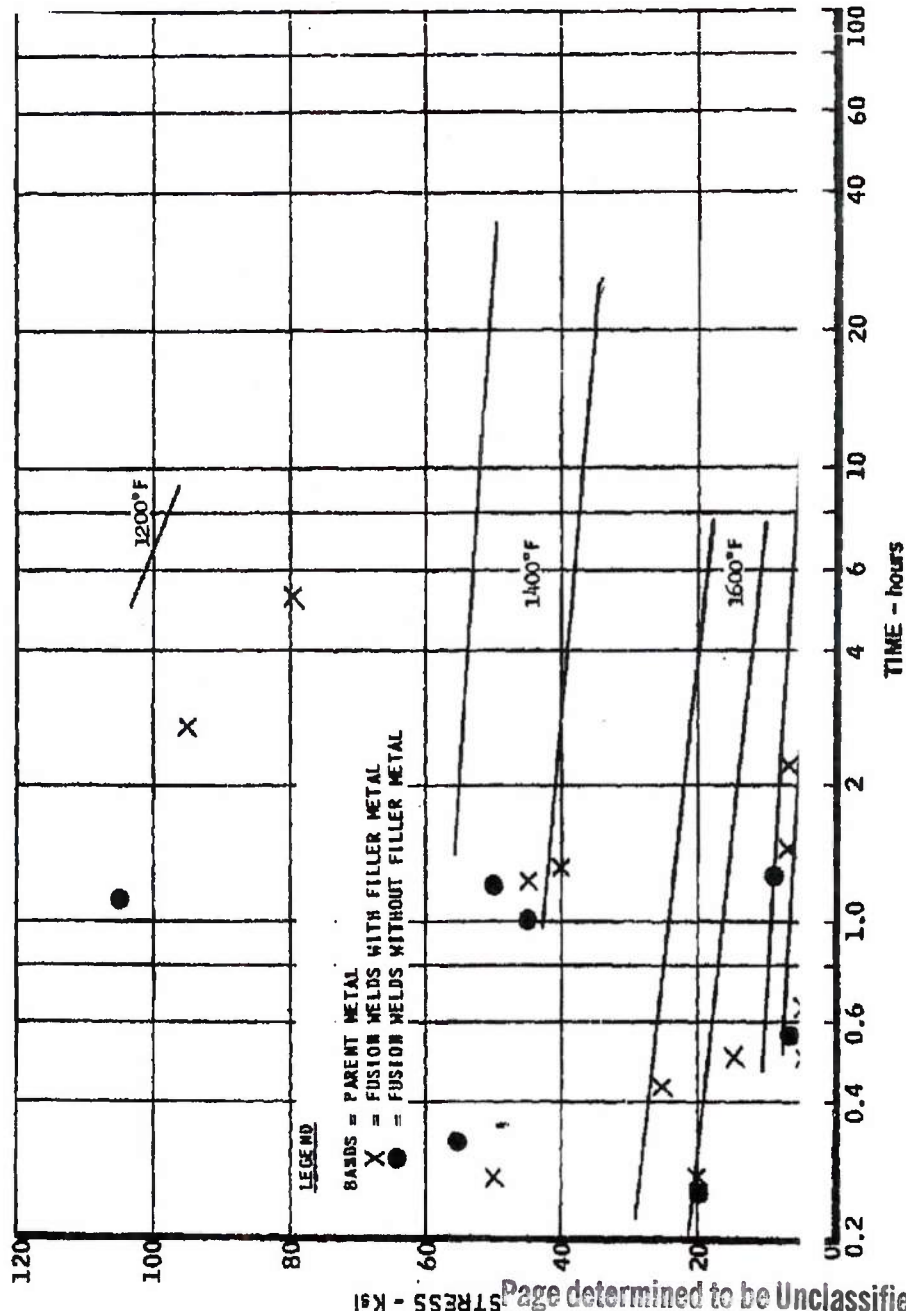
Page determined to be Unclassified  
Reviewed Chief, RDD, WHS  
IAW EO 13526, Section 3.5  
Date: MAY 29 2015

UNCLASSIFIED

**Marquardt**  
VAN NUYS, CALIFORNIA

5876

**1% CREEP OF R-235 ALLOY SHEET  
COMPARISON OF PARENT METAL AND FUSION WELDS**



Page determined to be Unclassified  
 Reviewed Chief, RDD, WHS  
 IAW EO 13526, Section 3.5  
 Date: MAY 29 2015

UNCLASSIFIED

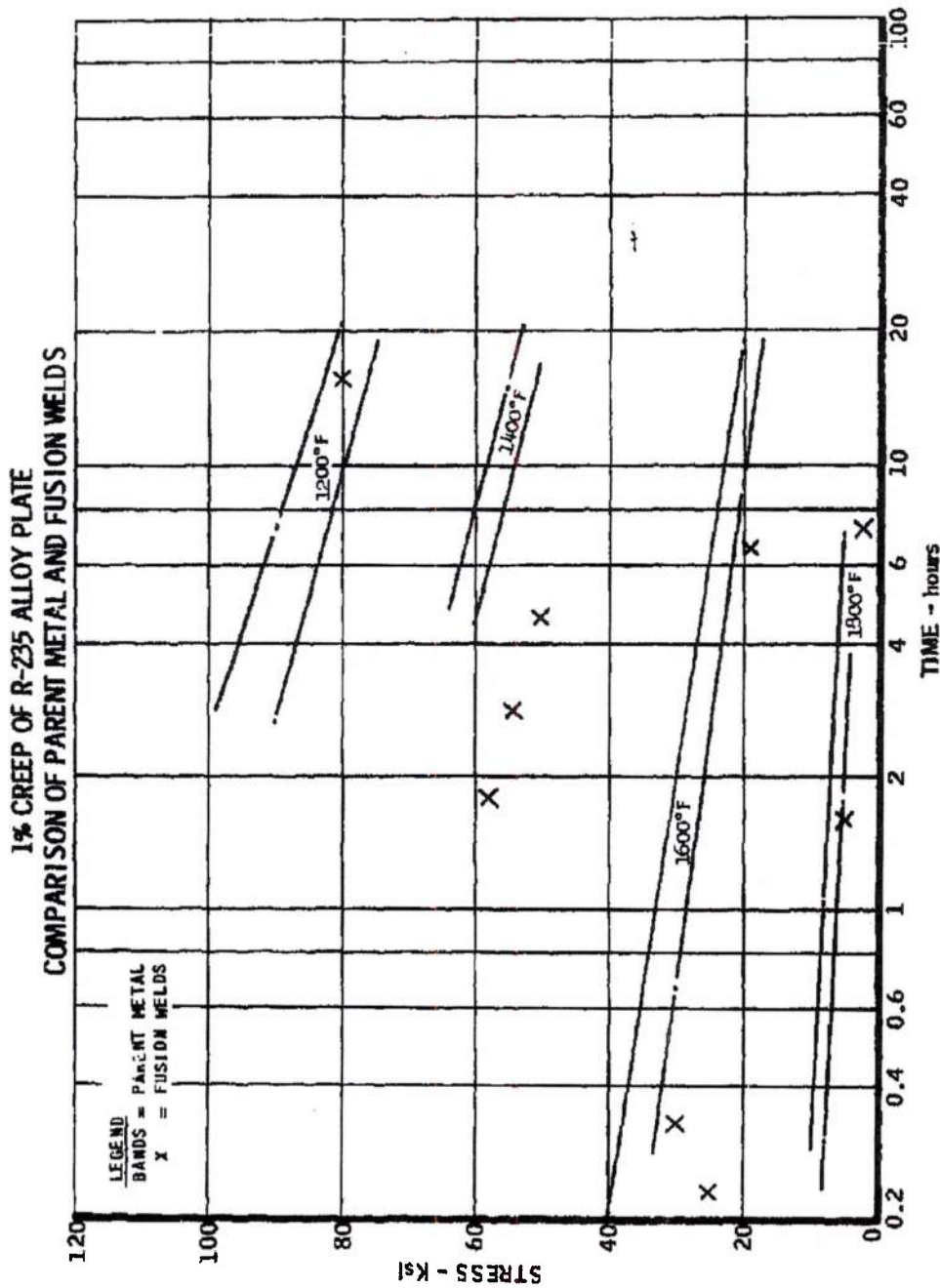
MAC 100

28B341

-239-

FIGURE 134

UNCLASSIFIED



UNCLASSIFIED

28B348

-240-

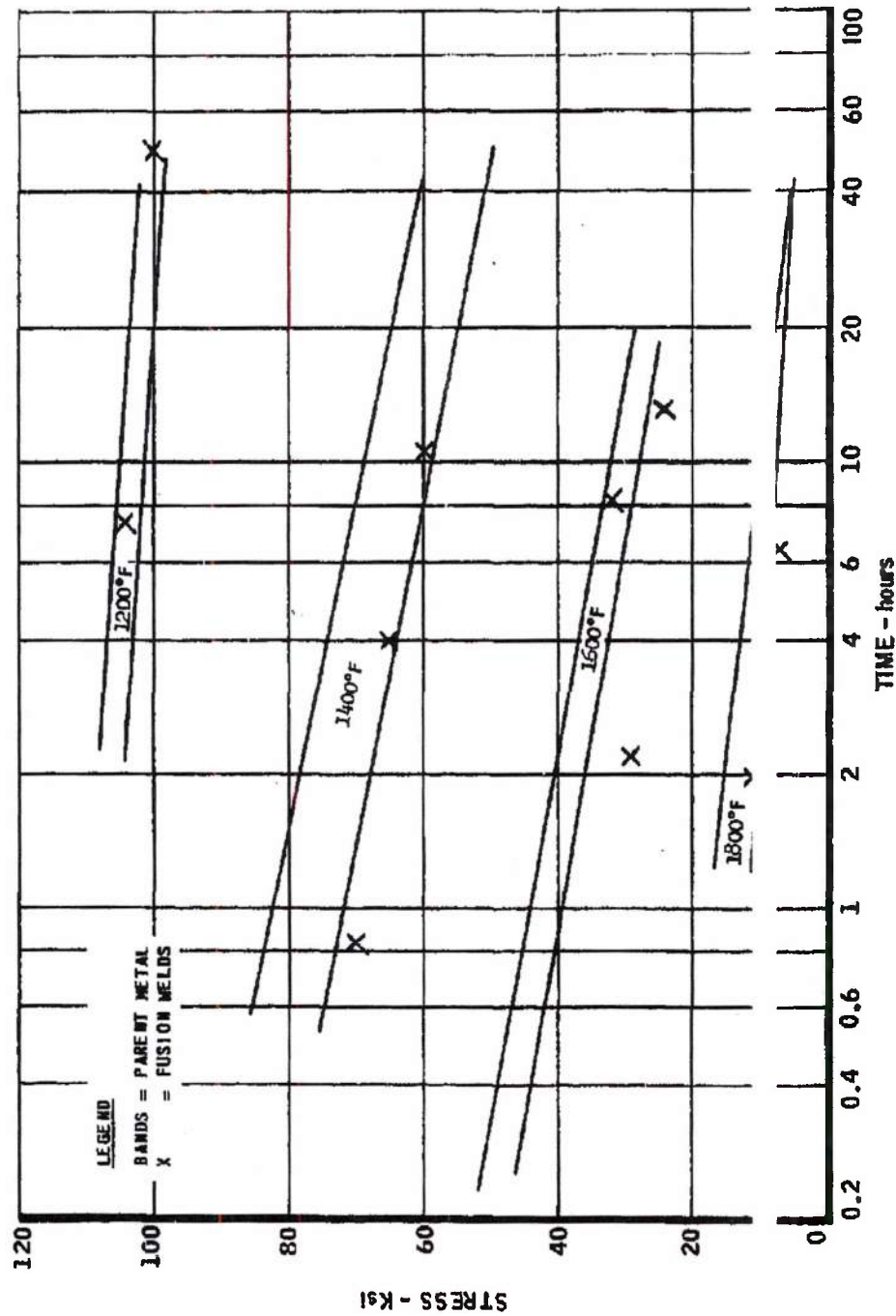
FIGUR 135

**The Marquardt Corporation**  
 VAN NUYS, CALIFORNIA

ORT 5876

UNCLASSIFIED

1% CREEP OF RENE 41 ALLOY SHEET  
 COMPARISON OF PARENT METAL AND FUSION WELDS



MAC AGI

UNCLASSIFIED

28B342

-241-

FIGURE 136



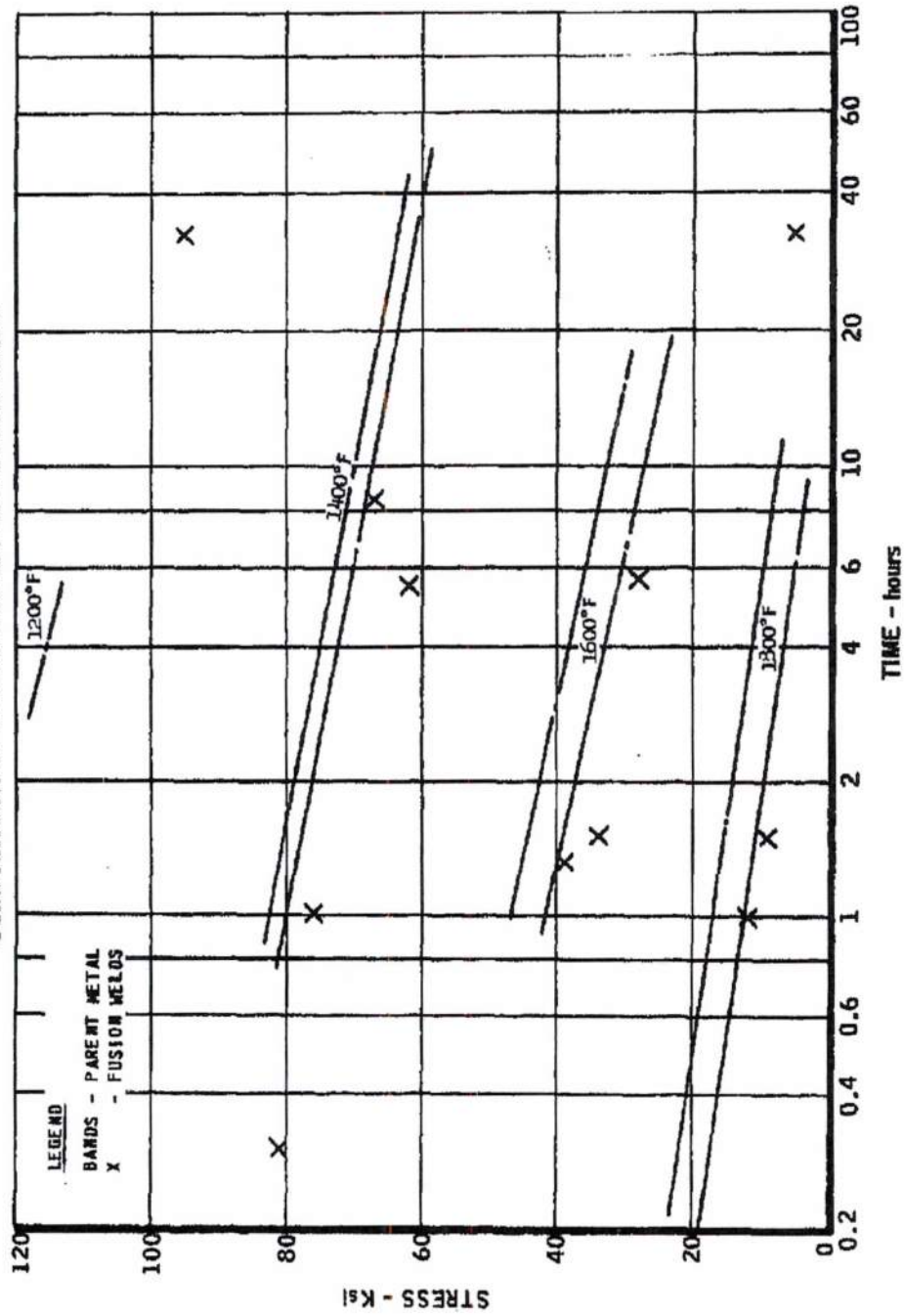
MAY 29 2015

THE *Marquardt*  
 CORPORATION  
 VAN NUYS, CALIFORNIA

REPORT 587

UNCLASSIFIED

1% CREEP OF RENE' 41 ALLOY PLATE  
 COMPARISON OF PARENT METAL AND FUSION WELDS



UNCLASSIFIED

MAC AGS

28B340

-242-

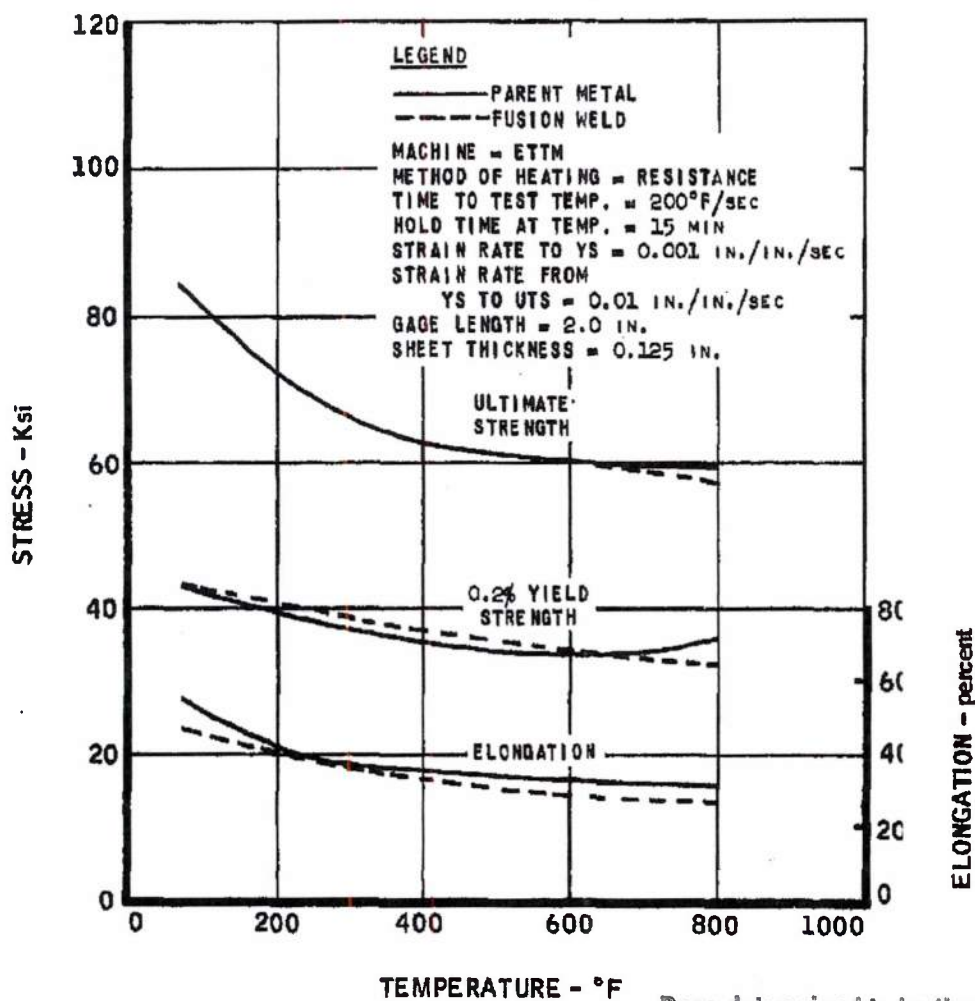
FIGURE 137

UNCLASSIFIED

THE *Marquardt*  
CORPORATION  
VAN NUYS, CALIFORNIA

ONT 5876

## TENSILE PROPERTIES OF TYPE 321 STAINLESS STEEL SHEET



Page determined to be Unclassified  
Reviewed Chief, RDD, WHS  
IAW EO 13526, Section 3.5  
Date: MAY 29 2015

MAC ACTS

UNCLASSIFIED

28A485

-243-

FIGURE 138

~~SECRET RESTRICTED DATA~~

*The Marquardt*  
CORPORATION  
VAN NUYS, CALIFORNIA

REPORT 58

~~ATOMIC ENERGY ACT OF 1954~~

Three points should be noted from examination of the data presented

(1) The change in mechanical properties of an alloy depending on whether the material is in the form of sheet or plate. This behavior is, of course, expected. The program for next year includes the testing of other forms of the alloys that may be used as structural members in the Pluto engine, such as forgings, castings, tubing, and wire so that the spread in design values for the alloys may be known.

(2) The allowances, if any, that must be made in design values to account for a welded structure and the welding procedure to be used. The M (metal alloy electrode, inert gas) process for welding is being developed for Hastelloy C alloy plate for further comparisons with the TIG process. Tests are planned for the coming year so that comparative results will be available.

(3) Inconsistencies within the same material due to alloy behavior or production history. In particular, the results of all tensile tests are based on one, or, at best, a few samples due to the large area to be covered for the year. It is necessary to test a large number of samples to establish statistical trends and reliability bands. The effort for the following year will be directed toward more complete and statistical data based on the results presented here to better define design values.

### 3.10.2 Beryllia Testing

#### Durability Tests

A program was undertaken in 1961 to provide experimental information on the durability of beryllia when exposed to the combined operating and environmental conditions expected during a typical mission profile for the nuclear ramjet missile. Data describing the mechanisms of hydrolysis and erosion are required to assess the effects of core deterioration on mission performance capabilities.

The beryllia specimens tested during 1961 were hot-pressed blocks one inch in diameter and one inch in length. The blocks were pierced by seven flow passages, each 0.20 inches in diameter. Two types of specimen materials were tested, pure beryllia and beryllia plus one percent of magnesia. Properties of the specimen materials tested were almost identical:

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2013

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

	<u>Beryllia</u>	<u>Beryllia</u> plus 1% <u>Magnesia</u>
Percent Theoretical Density	98 - 99	98 99
Grain Size (microns)	30 - 40	30 40
Modulus of Rupture (psi)		
Room Temperature	20 - 25,000	20 - 2 000
1500° F	15 - 18,000	.

A flow test rig was assembled that can supply one pound per second of vitiated air at temperatures up to 2500° F for periods up to and including ten hours. Fixed specific humidities of approximately 4 and 8 percent were imposed by using either hydrogen or propane for heat input. In a typical test run, four beryllia blocks were placed end to end in a specially designed and instrumented pipe section.

A total of 24 specimens (12 pure beryllia; 12 beryllia and one percent magnesia) were used during an accumulated 26 hours of testing. After exposure to the high-temperature, high-humidity air all specimens took on a glazed appearance, and almost all samples showed evidences of thermal cracking between adjacent holes. In a few cases these cracks were enlarged by corrosion. This effect can be seen in Figure 139.

Not enough tests have been performed to allow statistical evaluation of all the dependent variables associated with the hydrolysis phenomenon. However, sufficient experimental information has been obtained to establish trends and to serve as a preliminary basis for comparison with the results obtained by other investigators. Test results can be summarized as follows:

- (1) The hydrolysis mechanism is effectively nonexistent at temperatures below 2000° F.
- (2) In general, the samples with one percent magnesia exhibited 20 to 25 percent less total material loss than the pure beryllia under the same conditions.
- (3) Increasing the specific humidity from approximately 4 to approximately 8 percent had the apparent effect of increasing the erosion rate by as much as a factor of 4.
- (4) The average rate of material loss from the pure beryllia samples was approximately 4.5%/hr (by weight).

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~



UNCLASSIFIED

THE *Marquardt*  
CORPORATION  
VAN NUYS, CALIFORNIA

REPORT 58 6

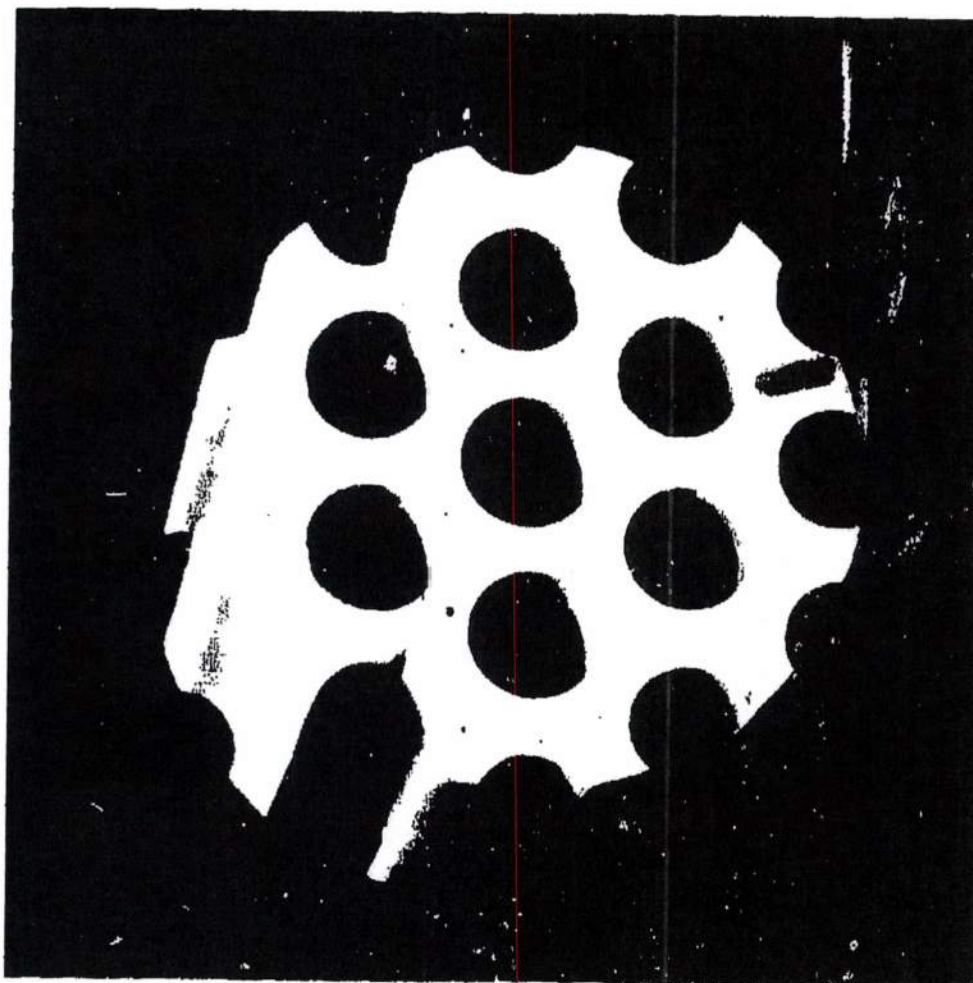


FIGURE 139 - Beryllia Hydrolysis Specimen L-6 (After Exposure)

Page determined to be Unclassified  
Reviewed Chief, RDD, WHS  
IAW EO 13526, Section 3.5  
Date: MAY 29 2015

MAC 403

UNCLASSIFIED

~~SECRET RESTRICTED DATA~~

SI 5876

~~ATOMIC ENERGY ACT OF 1954~~

- (5) The average rate of material loss from specimens with one percent magnesia was approximately 3.5%/hr (by weight).

The test conditions employed to date are considered rather severe with regard to the moisture content of the air. In order to more accurately simulate flight engine conditions (maximum specific humidity up to 3 percent at temperatures up to 2800° F), two new air heaters have been installed in the test facility. These heaters will permit testing at temperatures up to 3000° F with controlled humidity levels from zero to above 3 percent.

#### Thermal Shock Tests

In cooperation with Atomics International, Marquardt has performed a total of three tests to evaluate the thermal shock resistance of hot-pressed beryllia. The first two of these tests were performed in December 1960 and reported in the first period of 1961. The third test, conducted in mid 1961, was reported in Reference 8.

The purpose of these tests was to determine the magnitude of the thermal stresses induced in, and the structural damage suffered by beryllia specimens air-quenched from a high temperature. The three tests differed only with respect to specimen size and method of fabrication. The elements in the first test were one-inch thick hexagonal blocks, 3 1/4 inches across flats, with cored holes. The elements used in the second test were the same size but had drilled holes. The blocks used in the third test had drilled holes but were 5 1/4 inches across flats.

Each test module consisted of nine blocks contained in a specially designed holder. An assembled module is shown in Figure 140.

The beryllia blocks were extensively instrumented with thermocouples in order to obtain temperature profiles. Under typical test conditions the module temperature was raised to 2400° F with vitiated air (19 ppm 250 psig) at a rate calculated to keep the thermal stress at a safe level. With the module temperature stabilized at 2400° F, the air temperature was reduced instantaneously to approximately 1600° F. The thermal shock associated with this temperature change was manifested in the form of broken blocks and random hairline cracks. Comparison of pre- and post-test specimen weights indicated no loss of material due to erosion.

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

UNCLASSIFIED

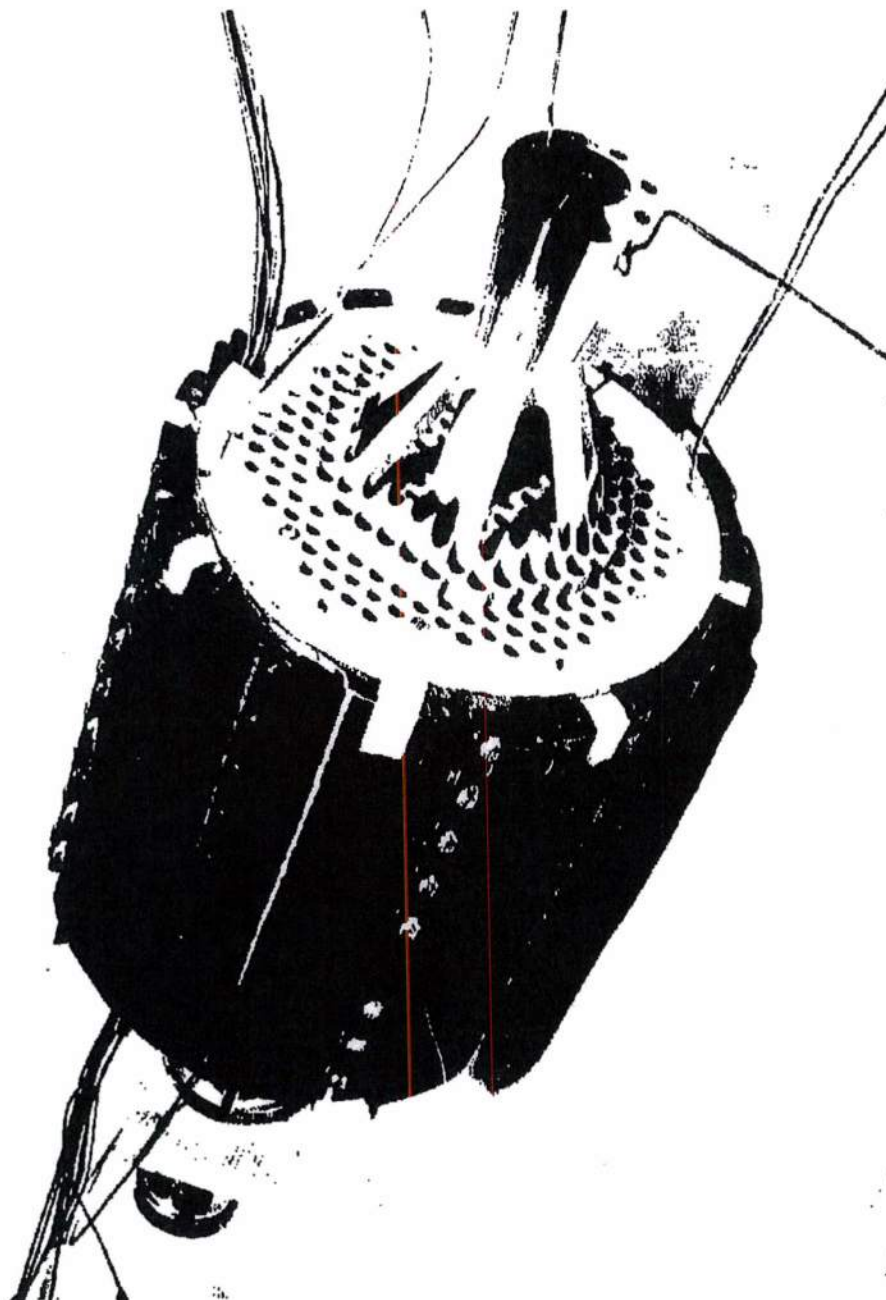


FIGURE 140 - Atomics International Hot Pressed Beryllia in Test Module

T2928-7

UNCLASSIFIED



MAY 29 2015

*The Marquardt*  
VAN NUYS, CALIFORNIA

REPORT 5876

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

Significant conclusions drawn from the three tests are as follows:

- (1) The capacity of the beryllia plates to withstand sharp temperature changes is directly related to method of fabrication and density uniformity.
- (2) The modulus of elasticity and/or rupture of the beryllia plate must be based on local density rather than bulk density.
- (3) The type of crazing and cracking encountered in the tests very probably would not adversely affect reactor operation.

### 3.10.3 High-Temperature Springs

An area of major concern in the design of the Pluto system is the control of differential thermal expansion between various components in the reactor support structure. The expansion of components must be accommodated without relieving necessary restraining forces or imposing overloads at critical regions. One method of controlling this expansion is the use of springs.

An extensive spring evaluation program was initiated and partially carried out during 1961 utilizing spring designs that could be incorporated into the basic structural supports of the Pluto reactor. Three types of springs are under investigation: (1) Belleville, (2) corrugated, and (3) plate.

In order to evaluate and verify the spring designs, experimental tests were conducted to provide performance data for each spring configuration. The tests were performed under simulated flight environmental conditions of temperature and vibration. Compression and tension tests of the corrugated springs and compression tests of the Belleville and plate-type springs were conducted to determine load-deflection performance and spring relaxation under conditions of normal dynamic cycling, rapid repetitive cycling, and vibration at both ambient and elevated temperatures to 1400° F for extended time periods.

Rene' 41 alloy material was selected for all springs as the best available high-temperature alloys for the anticipated operating conditions.

#### Belleville Springs

Figure 141 shows a typical 10-spring stack of Belleville springs. A single spring is 0.10 inches thick, 2.00 inches in outside diameter, 0.875 inches in internal diameter, and 0.045 inches in coned height. Test configurations consisted of individual Belleville springs, 10 springs stacked in a series arrangement, and 6 springs stacked in parallel-series combination. The spring tester is shown in Figure 142. Instrumentation included a load cell to indicate loads up to 5000 pounds, a direct reading dial indicator for deflection data, and temperature readout.

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

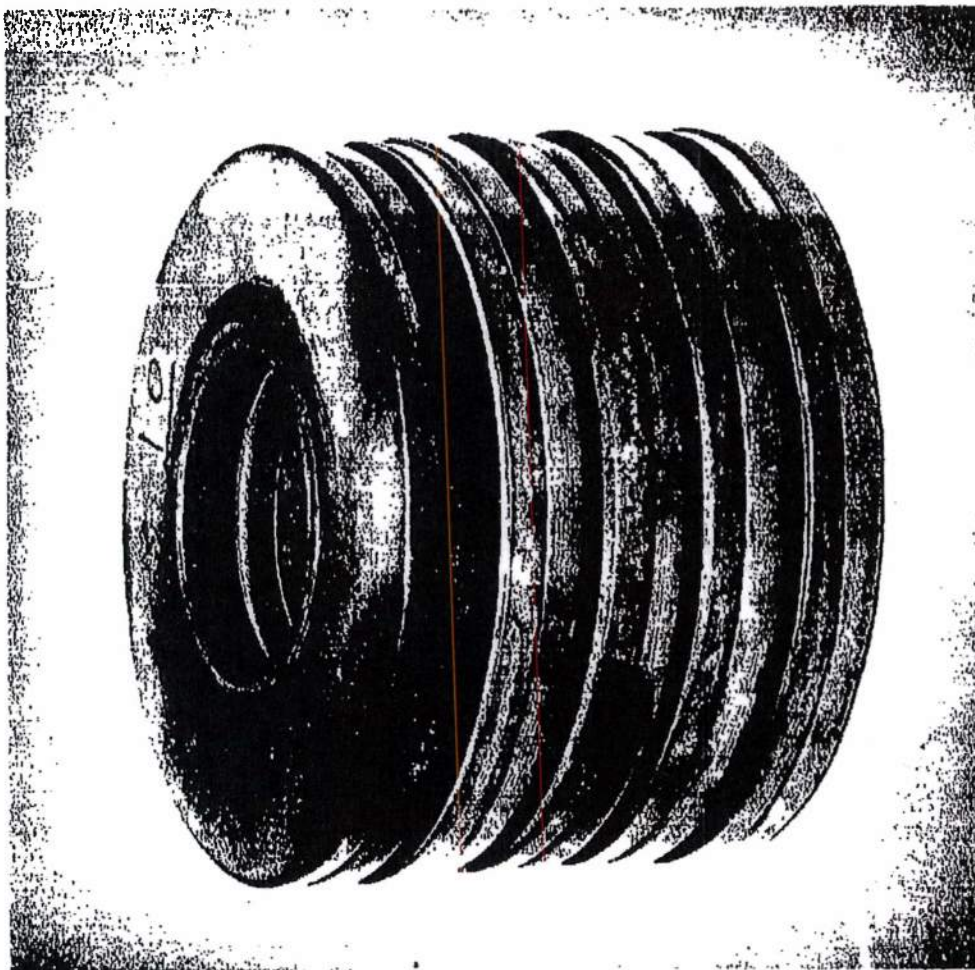


MAY 29 2015

THE *Marquardt*  
CORPORATION  
VAN NUYS, CALIFORNIA

REPORT 5876

UNCLASSIFIED



SHRIMP ANTENNULAR TOXIN - SHRIMP TOXIN - SHRIMP TOXIN

3879-3

UNCLASSIFIED

UNCLASSIFIED

*The Marquardt Corporation*  
VAN NUYS, CALIFORNIA

5876

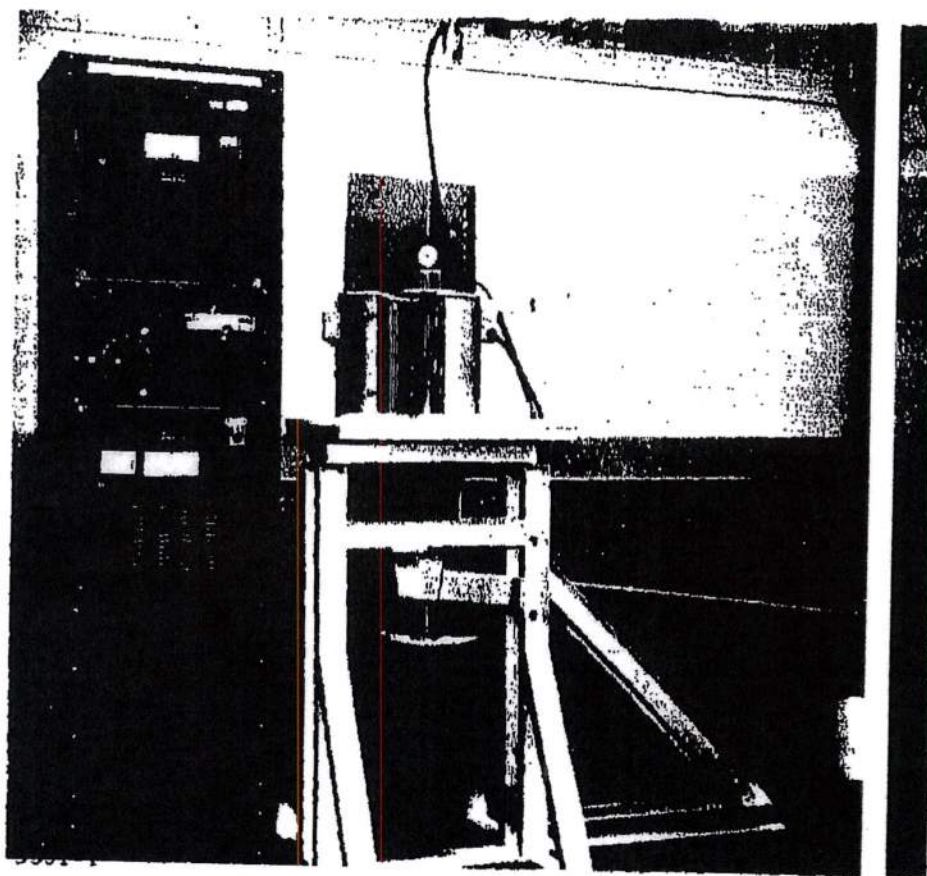


FIGURE 142 - Belleville Spring Tester

MAC AGO

UNCLASSIFIED

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

For the vibration tests, the spring tester was modified by replacing the load cell with a pneumatic piston vibrator linked through the spring tester as shown in Figure 143.

Results of the load-deflection and vibration tests for the Belleville springs can be summarized as follows:

(1) In general, during the first few load cycles, both single springs and stack configurations showed initial relaxations, very close to predicted value.

(2) At ambient temperature and 1200° F, the springs demonstrated very little additional relaxation with continued load cycling. However, at 1400° F the springs indicated an increased rate of relaxation with additional load cycling.

(3) The constant deflection test for the extended period (10 hours) and load cycling for the extended time (accumulative 10 hours) resulted in small loss of load-carrying capability at ambient and 1200° F, whereas at 1400° F the loss was considerable.

(4) Evaluation of spring performance under vibration conditions at 1200° F and 1300° F was inconclusive due to test equipment difficulties.

Conclusions that may be drawn from these results are summarized follows:

(1) Load-deflection performance of the springs verified the trend of design; i.e., the springs were designed with a load-deflection curve approaching linearity.

(2) Belleville springs fabricated to the present design from Rene 4 alloy are satisfactory for use at temperatures to 1200° F. In the 1300 to 1400° F temperature range, spring performance will be marginal.

(3) Spring performance above 1300° F is apparently affected by work hardening and material creep. Indications are that these detrimental characteristics can be circumvented by limiting deflections to less than 80 percent the spring deflection capability.

(4) Because the springs undergo an initial relaxation, they should be load-deflection cycled prior to final assembly.

~~SECRET RESTRICTED DATA~~

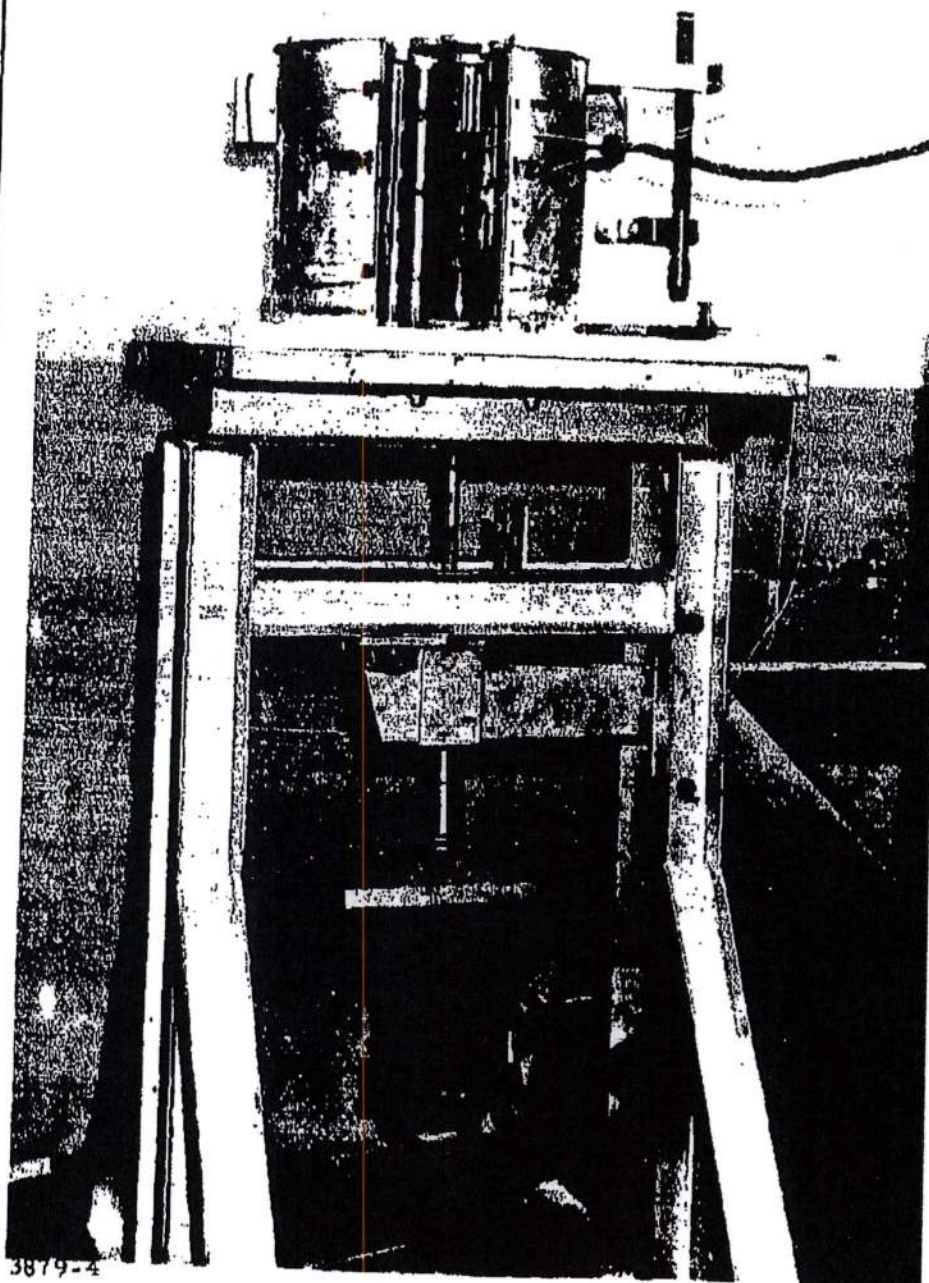
~~ATOMIC ENERGY ACT OF 1954~~



UNCLASSIFIED

*The Marquardt*  
CORPORATION  
VAN NUYS, CALIFORNIA

PORT 5876



3879-4

FIGURE 143 - Belleville Spring Tester with Vibrator Installed

UNCLASSIFIED



~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

### Corrugated Springs

Figure 144 shows the configuration of the corrugated springs used in the evaluation tests. In the figure, the longer spring is 11.3 inches long and has a nominal thickness of 0.100 inches. The shorter spring is 10.2 inches long with a nominal thickness of 0.125 inches.

Ambient temperature tests of corrugated springs were performed on the Baldwin Universal Test Machine at the Marquardt Materials and Process Laboratory. Figure 145 shows this setup. The springs were instrumented with strain gages to obtain tensile and compressive strain data at the inner and outer convolutions of the spring. Load, deflection, and strain values were recorded. The elevated temperature test setup is shown in Figure 146.

Rapid cycling tests were performed on corrugated springs at ambient temperature and 1400° F to document spring fatigue characteristics. Figure 147 shows a spring being cycled at 1400° F in the Elevated Temperature Test Machine. Load, deflection, temperature and cycling frequency were recorded. The following results were obtained:

(1) No relaxation (permanent set) occurred during normal tension cycling tests at maximum test conditions of 0.280-inch extensions, 482-pound loads, and temperatures ranging from ambient to 1400° F.

(2) Load-deflection values, obtained from the normal tension tests, matched predicted performance for both ambient and elevated temperatures.

(3) Under rapid tension cycling tests at 1400° F, spring relaxation occurred and appeared to be linear and continuous for individual test runs of 1 1/2 hours, 4 1/2 hours, and 6 hours. This was true for both the 0.100- and 0.125 inch thick springs. Maximum deflection for these tests was 0.279 inches with a maximum load of 430 pounds. Cumulative relaxation values for a series of short tests on a given spring exceeded the values obtained for a continuous test on a similar spring over the same total time period. Also, the composite time-relaxation curve was nonlinear for the series of short tests.

(4) Rapid tension cycling of one 0.100-inch spring to 0.295-inch extension (332-pound load) at 1200° F temperature for two separate six-hour periods did not produce elongation.

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

UNCLASSIFIED

ORT 5876



FIGURE 144 - Corrugated Side Support Springs

3566-1

MAC AGD

UNCLASSIFIED



Page determined to be Unclassified  
Reviewed Chiet, RDD, WHS  
IAW EO 13526, Section 3.5  
Date:

MAY 29 2015

THE  
*Marquardt*  
CORPORATION  
VAN NUYS, CALIFORNIA

REPORT 5876

UNCLASSIFIED

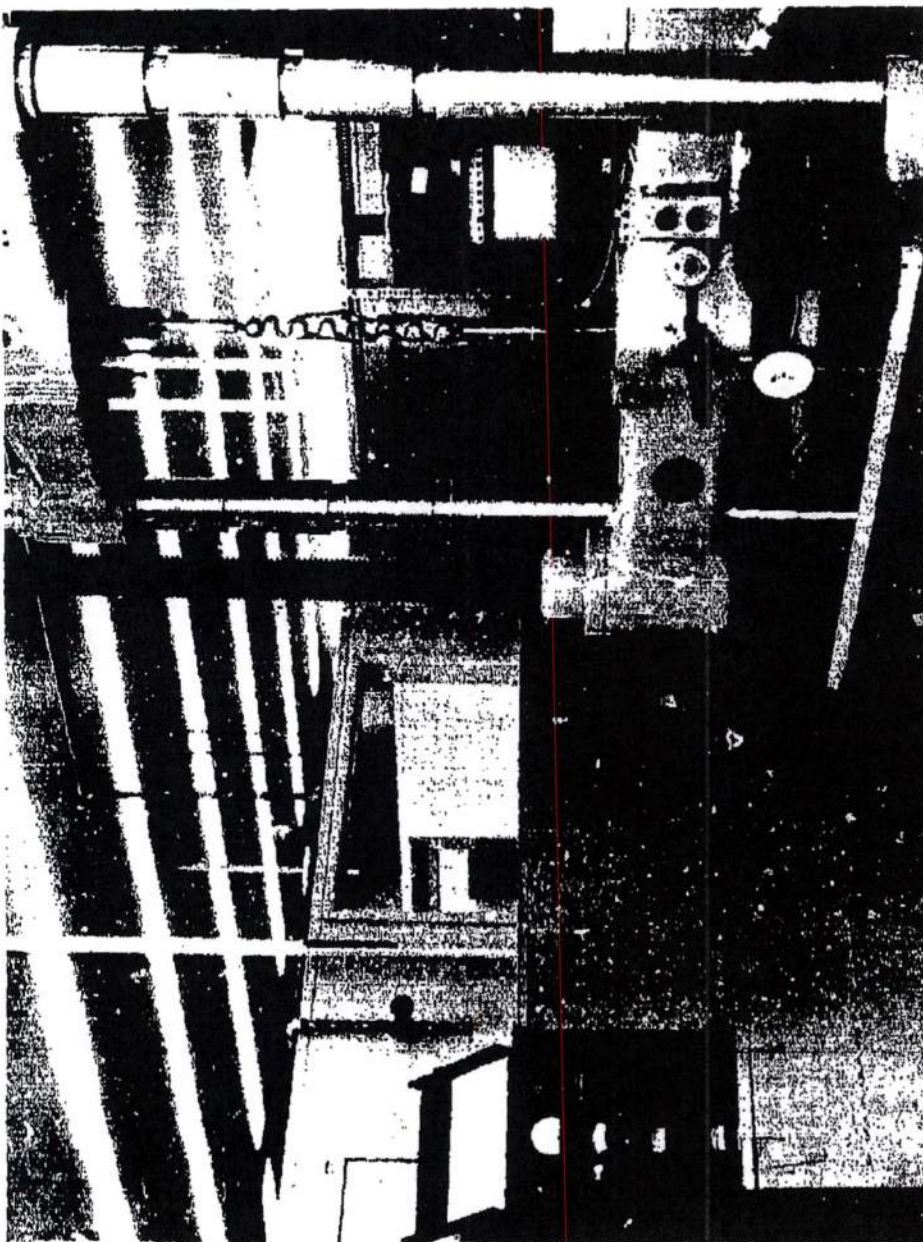


FIGURE 145 - Corrugated Side Support Springs Installed in Baldwin

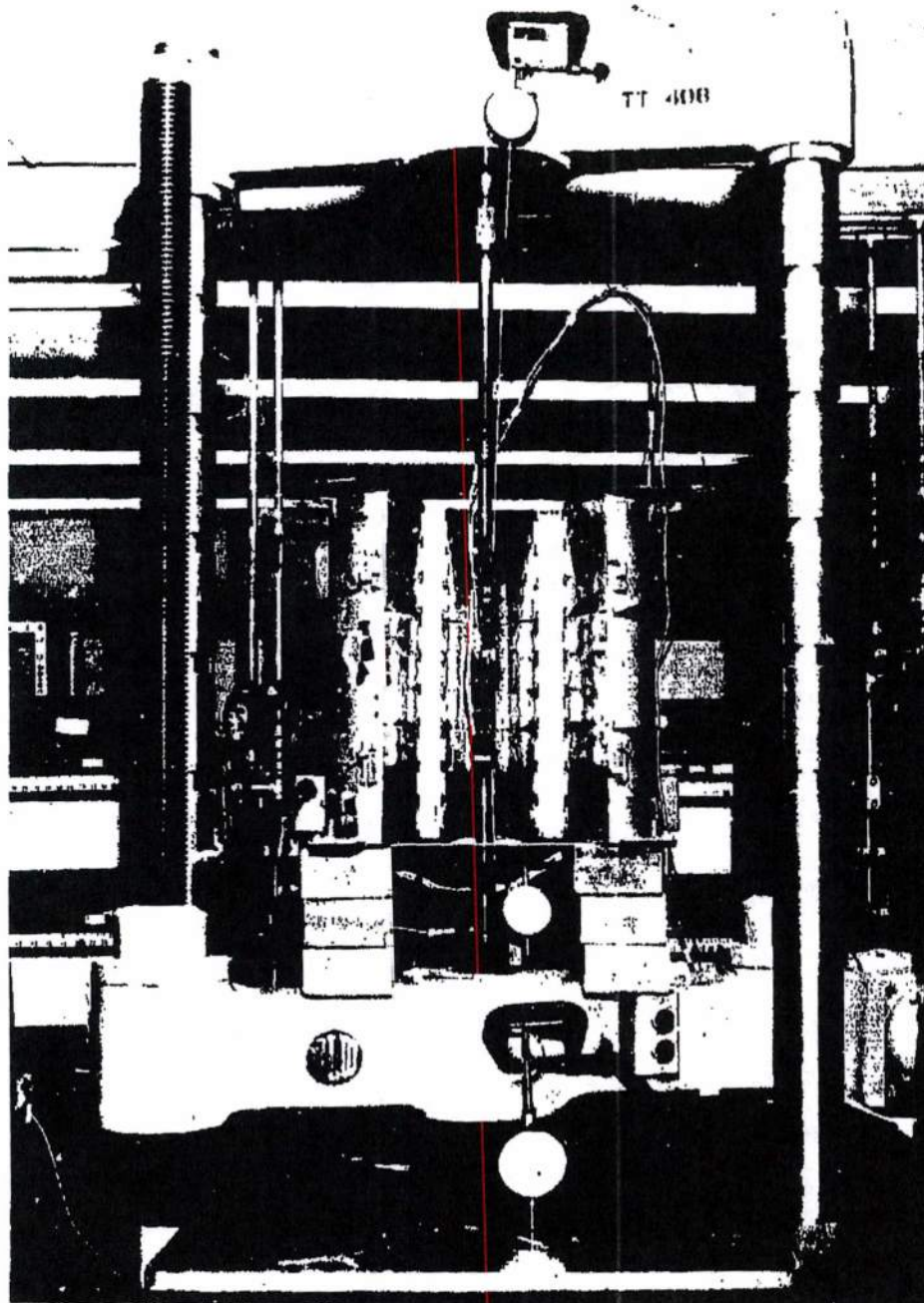
mentation

3566-5

MAC AGS

UNCLASSIFIED

UNCLASSIFIED



3566-7

FIGURE 146 - Elevated Temperature Test of  
Corrugated Side Support Spring

UNCLASSIFIED



UNCLASSIFIED

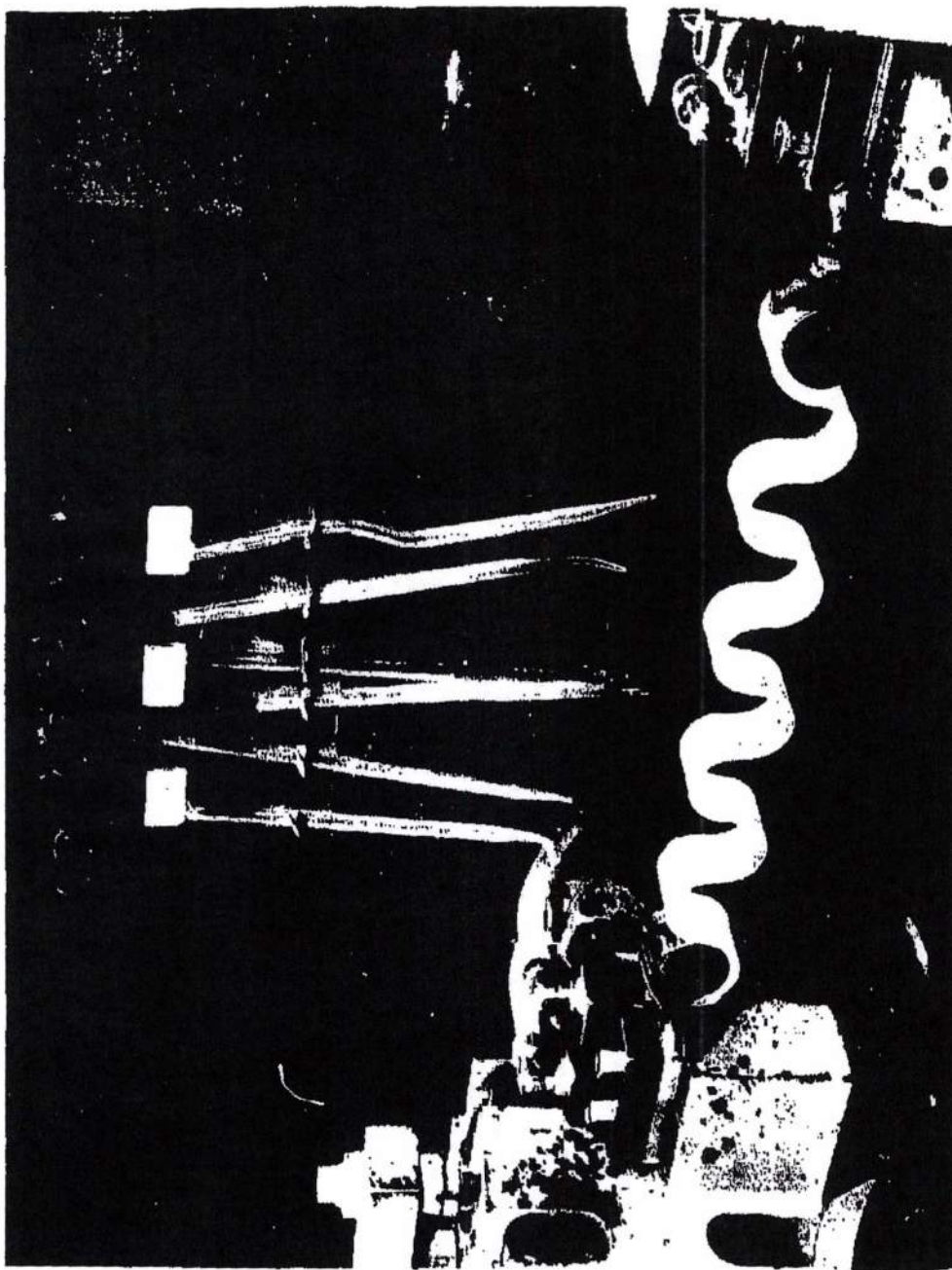


FIGURE 147 14000 PSI of Compressed Gas in Flashed  
Temperature Test Machine

3566-9

MAC AGS

UNCLASSIFIED

~~SECRET RESTRICTED DATA~~

THE *Marquardt*  
CORPORATION  
VAN NUYS, CALIFORNIA

5876

ATOMIC ENERGY ACT OF 1954

From these results, the following conclusions were reached:

- (1) Corrugated springs can be adequately designed by "curved beam" formulae to meet requirements of a particular application.
- (2) Corrugated springs are particularly sensitive to shape and tolerance discrepancies. To assure acceptably uniform performance characteristics, strict manufacturing quality control must be maintained.
- (3) Material creep and work-hardening experienced in the 00° F rapid cycling tests can be eliminated if tension bending stresses do not exceed approximately 75 percent of the allowable tensile stress for zero creep at that temperature.
- (4) The magnitude of corrugated spring relaxations resulting from rapid cycling generally have a negligible effect upon spring rate during subsequent testing, provided the induced tension bending stresses do not exceed approximately 60 percent of the allowable tensile stress for zero creep.

#### Plate Springs

Figure 148 shows the plate springs as tested in this program. The plate springs were tested for load-deflection characteristics at room temperature and elevated temperature in the Baldwin Test Machine in a test setup similar to that used for the corrugated springs. No rapid cycling testing of these springs was performed. Problems arose during the testing that resulted in erratic and inconclusive test results. Further testing of plate springs is planned for 1962.

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

ATOMIC ENERGY ACT OF 1954

Page determined to be Unclassified  
Reviewed Chief, RDD, WHS  
IAW EO 13526, Section 3.5  
Date:

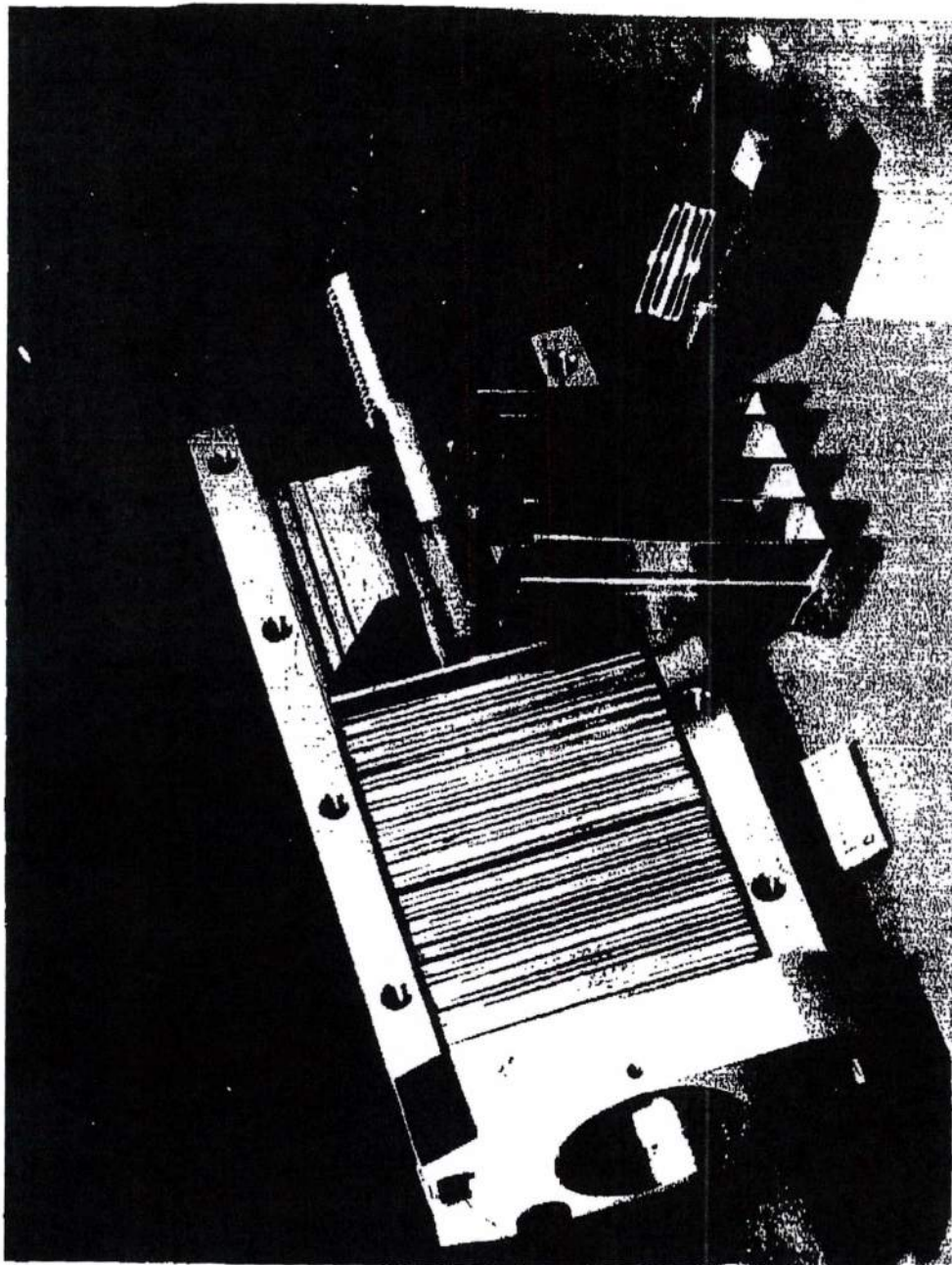
MAY 29 2015

UNCLASSIFIED

TPE  
*Marquardt*  
CORPORATION  
VAN NUYS, CALIFORNIA

REPORT

76



and Compression Testing

3718-5

UNCLASSIFIED

-260-





~~SECRET RESTRICTED DATA~~

ORR 5876

ATOMIC ENERGY ACT OF 1954

#### 4.0 PROPULSION SYSTEM CONTROLS

##### 4.1 GENERAL STATUS

During the year 1961 a balanced program was planned for the development of Pluto propulsion system controls. The controls activities fell into three logically separated, although not independent, categories. The categories are generally described as (1) system analysis, pertaining to the generation of requirements and specifications for the control system and its components; (2) control system components, pertaining to the design, development, and testing of sensors, electronic computing devices, and pneumatic actuators; and (3) irradiation testing, pertaining to the investigation of materials, components, and design techniques to permit sustained operation of controls devices in a nuclear environment.

During the course of the year's activities it became obvious that more rapid progress was being made in the development of electronic computing devices and sensors than was being made in the development of high-temperature pneumatic actuators. Thus, in order to maintain a balanced program leading to coordinated completion schedules for system testing, portions of the electronic and sensor development programs were curtailed to place increased budget emphasis upon pneumatic actuator development. In particular, a two-phase program was initiated to evaluate, under controlled test conditions, the friction and wear characteristics of selected materials and the relative advantages of various lubrication systems for use at high temperatures.

The following sections describe the 1961 activities in the above-mentioned categories.

##### 4.2 CONTROL SYSTEMS ANALYSIS

###### 4.2.1 Minimum Startup Interval

One of the limitations that determines the minimum value of engine start-up time is the dynamic response of the nuclear instrumentation used in the ground control system, such as log count rate (LCR) and ln n circuits. These circuits operate with low pulse repetition rates and low current inputs.

A dynamic closed-loop analysis has been performed on the external ln n loop incorporating mathematical models of typical existing nuclear instrumentation. The limiting instrumentation characteristics are the smoothing filter dynamics in the LCR circuits that are dominant in the lower level channels. In this analysis the following assumptions and conditions were used:

~~SECRET RESTRICTED DATA~~

ATOMIC ENERGY ACT OF 1954



~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

(1) The primary control parameter is either  $\ln n$  or inverse period from source level to the power level at which the inflight control system is switched into control. The system is operated closed-loop, where continuous control of  $\ln n$  or inverse period is provided.

(2) Typical commercially available nuclear instrumentation is used in the ground nuclear control system.

(3) The automatic, programmed command ( $\ln n$  or inverse period) was assumed to be one-decade step inputs, for which instrumentation response characteristics were available. The reactor was restricted to periods longer than 1 second for two reasons: (a) the outputs from the nuclear instrumentation represent maximum rate-of-change quantities that the instrumentation is capable of providing for input decade step commands, and (b) an inverse period override is authorized (monitored for selection) so that the actual reactor period cannot be less than 1 second.

(4) The source level is taken at 1 milliwatt.

The internal  $\ln n$  loop was analyzed for two reasons: this loop is common to all outer control loops, and the dynamics of the internal  $\ln n$  loop are the limiting dynamics in the outer control loops using  $\ln n$  or inverse period as primary control parameters. Reactor temperature during the interval from source level to about 1 percent design point power is near ambient. Thus, core temperature is of no practical use as a control signal during rapid startups.

The analysis indicates that, with the nuclear instrumentation included, the  $\ln n$  loop is stable when the coarse rod control subsystem and inflight control reactor compensator are removed. Because the coarse rod control subsystem is used only to compensate for large reactivity changes due to temperature coefficient effects and long term poison effects, the coarse rod is not needed for control during the interval from source insertion to the launch power level. In this interval, the reactor temperature remains near ambient and reactivity changes due to temperature changes are negligible. Use of the coarse rod control subsystem for scram is not excluded. The closed-loop response for the internal  $\ln n$  loop (Reference 26) was studied using the basic engine control system configuration with the addition of instrumentation dynamics derived from experimental data. These data were furnished by General Dynamics/Electronics and appeared in the Twentieth Quarterly Progress Report.

During startup from source level to the power level at which control is transferred from the ground equipment to the inflight control system, the ground nuclear instrumentation and control equipment are part of the internal  $\ln n$  loop (the control equipment consists, in part, of counters, ion chambers, LCR

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

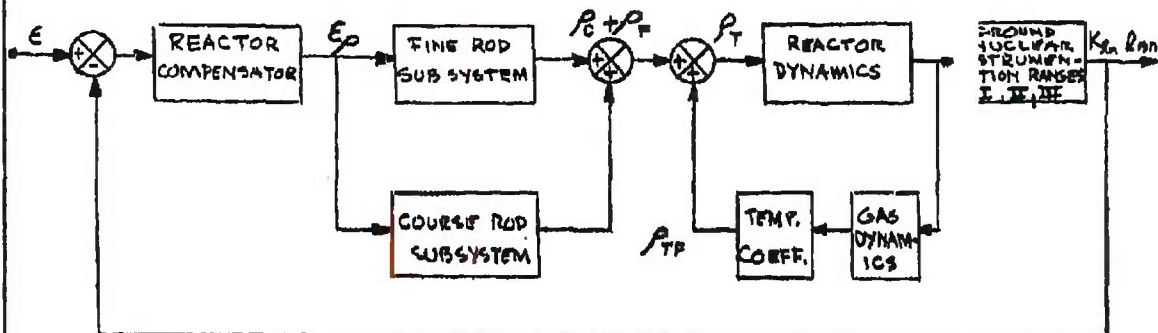


PORT 5876

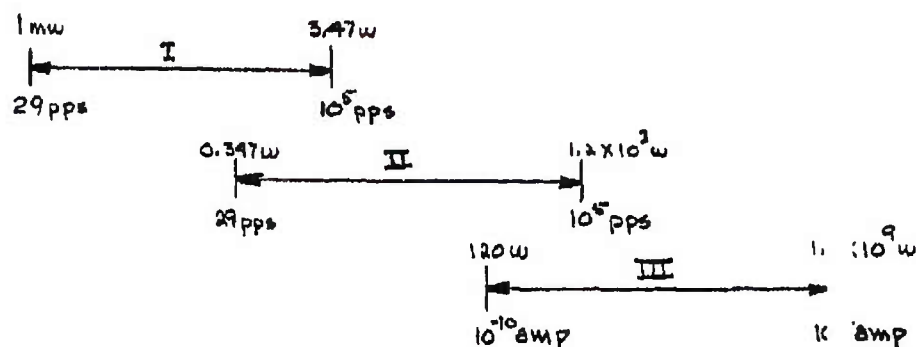
~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

circuits, and  $\ln n$  amplifiers). The signal smoothing characteristic of the LCR and  $\ln n$  circuits are a function of the flux level and contribute significant amounts of phase shift at low counting rates and low current inputs to the  $\ln n$  amplifier. The effects of these dynamics in the control loop were considered by insertion of appropriate dynamic equations for the blocks in the internal  $\ln n$  loop that is shown here.



Detailed mathematics of these functional blocks, except the instrumentation, will not be included here as this information is fully discussed in Reference 26. The following sketch of instrumentation channels and ranges indicates the values assumed with typical counter and ion chamber sensitivities and Pluto flux levels.



**MAC AGR**

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

~~SECRET RESTRICTED DATA~~

REPORT 56 6

~~ATOMIC ENERGY ACT OF 1954~~

An overlap of one decade has been included between the ranges. The switching points between ranges were taken at the lowest level of each range, because these are the points at which the time response of the instrumentation is the slowest, and hence these points represent the worst conditions possible for fast automatic control. As the power level increases, the time response of the instrumentation also improves until it is no longer a limiting factor in the local dynamics.

To determine a mathematical model of the instrumentation, a theoretical curve was fitted to the experimental data provided by the manufacturer. The theoretical transfer function that describes this curve was then used to represent the instrumentation in the internal loop.

At the very low power levels during startup there is no airflow through the reactor, and the core is at ambient temperature. This condition results in reducing the transfer function of the core to the form of a simple integration with a very low gain. When the effect of the temperature coefficient is added, the gain through the internal temperature feedback of the reactor is so low that the reactor can be treated as an open loop. This means that the phase shift for the internal loop at this condition starts at  $-180^\circ$  for zero frequency as compared to  $0^\circ$  at the higher temperature inflight conditions where the gas dynamics have an effect. If the instrumentation dynamics of Ranges I and II are added to this loop, an instability results. To overcome this condition it is necessary to remove the coarse rod subsystem and the reactor compensator from the loop. (It should be noted that the coarse rod subsystem has a free integration with second order dynamics and that the basic function of the coarse rod is to control the reactivity effects of large temperature changes occurring during launch and long term positioning. These destabilizing dynamics are eliminated by holding the coarse rod subsystem inoperative during initial fast startup at low power levels.)

As the power level increases, the instrumentation dynamics improve and are no longer the limiting factor in the closed-loop response. Since the same LCR circuit is used for both Ranges I and II, the closed-loop dynamics for these two ranges are identical. The closed-loop rise times for these ranges using step inputs of one decade each were calculated for the entire range, and the fastest possible controlled power profile for Ranges I and II using these dynamics has been plotted in Figure 149.

In Range III, the internal amplifier is in the loop. The internal amplifier has no integration and a smaller time constant; hence, the instrumentation dynamics do not limit a power rise to a period slower than 1.0 second. The closed-loop rise times for Range III were calculated for one-decade steps and were included in Figure 149.

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~



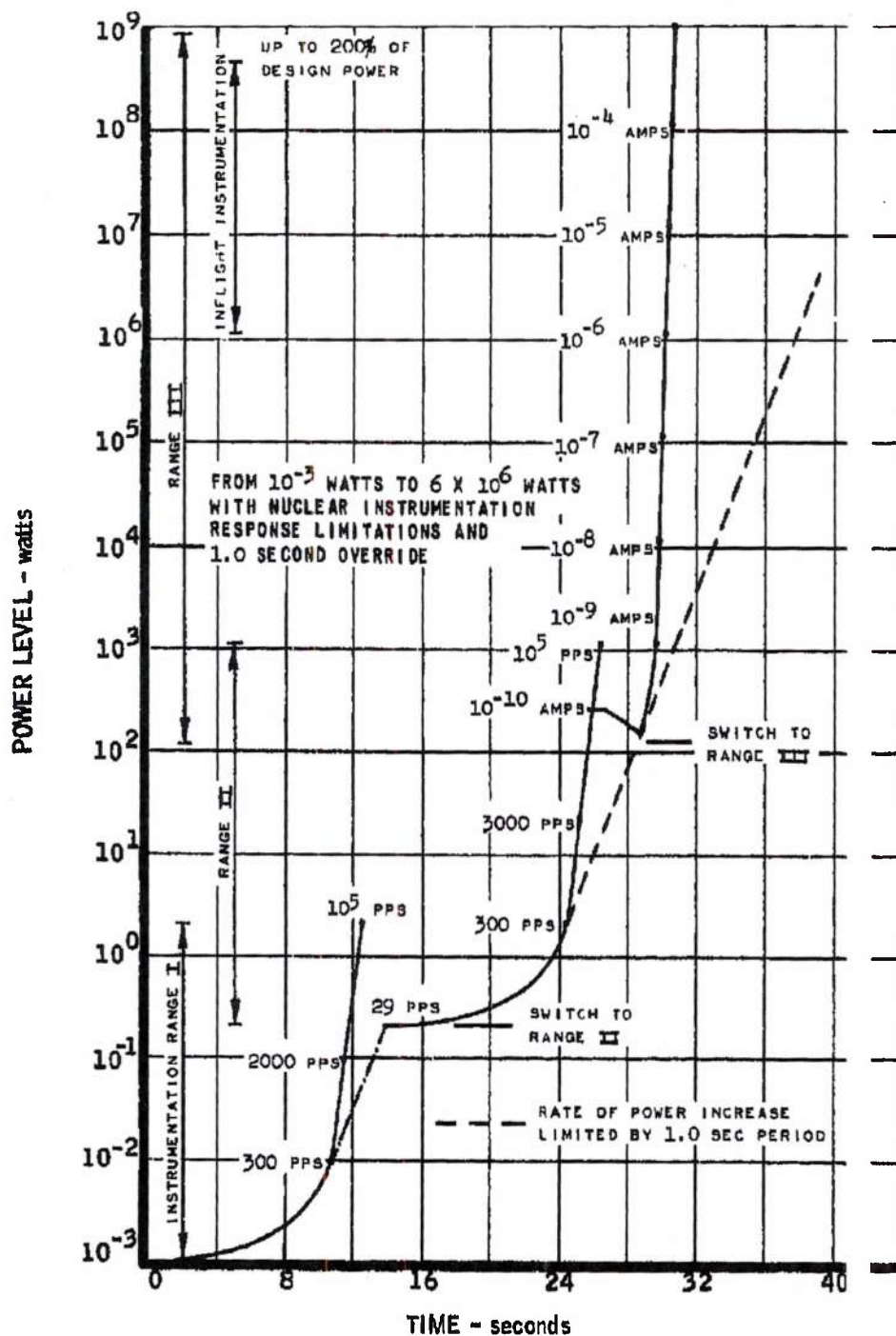
~~SECRET RESTRICTED DATA~~

*The Marquardt Corporation*  
 VAN NUYS, CALIFORNIA

PORT 5876

~~ATOMIC ENERGY ACT OF 1954~~

# REACTOR POWER - REAL TIME PROFILE



MAC A573

~~SECRET RESTRICTED DATA~~

N22G588

~~ATOMIC ENERGY ACT OF 1954~~

-265-

FIGURE 149



MAY 29 2015



REPORT 58

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

Figure 149 shows the minimum time in which the reactor could be automatically taken up to 1 percent of design power when the worst possible dynamic ranges of available instrumentation are included with a switching overlap of one decade, and a 1.0-second period override. Source strength can be increased to reduce this time and improve system stability. To reduce the time further a smaller overlap between the ranges may be utilized, and much of the instrumentation limitation can be avoided. The minimum time required under the worst conditions to attain 1 percent of design power from source insertion is approximately 39.0 seconds.

#### 4.2.2 Control Response For Inlet Restart at Low Altitude Condition

A simplified dynamic analysis has been completed to determine whether it is feasible, from an airframe maneuvering point of view, to incorporate in the Pluto inlet design the capability of restart during the low-altitude penetration phase of the mission.

The main objective of the study was to determine the time available to detect an unstarted inlet condition, to perform the necessary controls function, and to restart the inlet with the following limitations:

- (1) The inlet cannot be restarted at a Mach number less than 2.75
- (2) The inlet cannot be restarted at an angle of attack greater than 7.0 degrees
- (3) An appreciable loss of altitude from the 1,000-foot cruise condition is prohibitive

It was determined that the optimum airframe maneuver during an unstarted condition is to hold altitude and to allow the vehicle to increase the angle of attack as required. In this mode the forward velocity will decrease until restart is accomplished, or until speed drops below Mach 2.75. It is shown that, using this type of maneuver, the vehicle will slow down to Mach 2.75 in approximately 3 seconds with very small changes in altitude or angle of attack, due to the action of the autopilot (Figure 150). This time interval was established assuming that the thrust is equal to zero from the instant of unstart until the inlet is restarted, and that the drag is increased during this period by approximately 7 percent (Figure 151). These values of thrust and drag represent the most pessimistic case.

There would be no advantage to a pitchup maneuver to increase altitude with an unstarted inlet unless the minimum Mach number at which restart can be

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

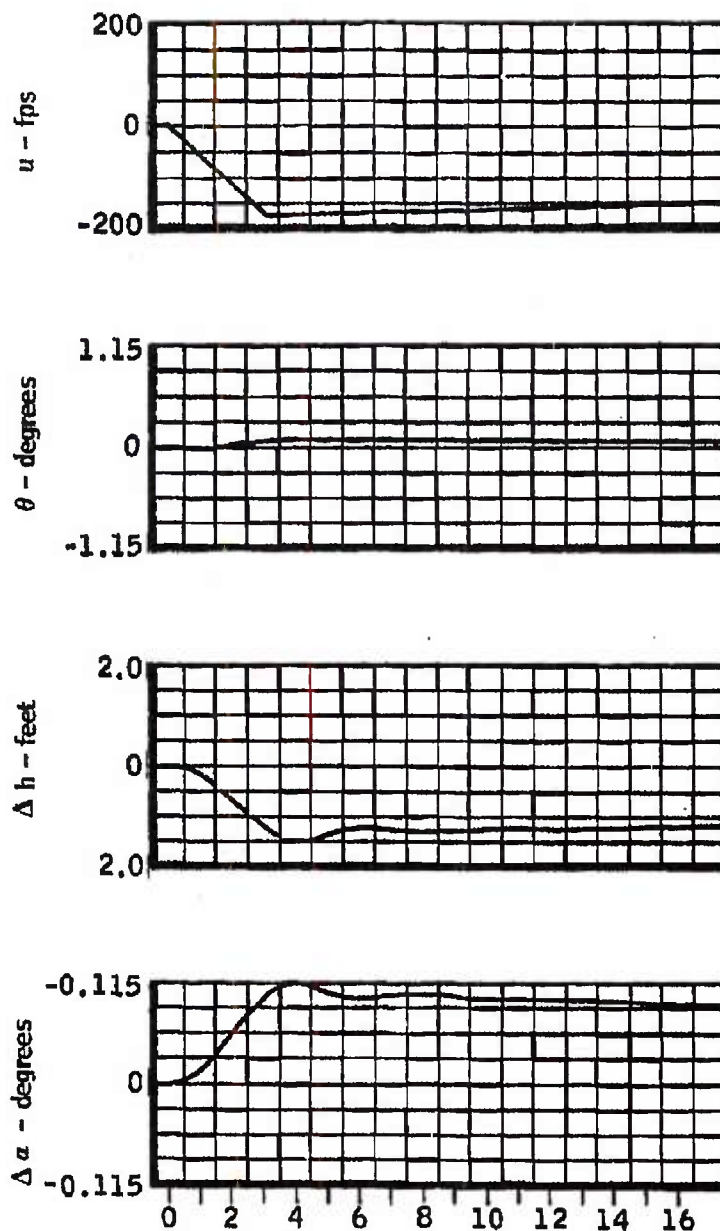
~~SECRET RESTRICTED DATA~~

*The Marquardt Corporation*  
VAN NUYS, CALIFORNIA

PORT 5876

~~ATOMIC ENERGY ACT OF 1946~~

### AIRFRAME TRANSIENT RESPONSE DURING PERIOD OF INLET UNSTART AND RESTART



~~SECRET RESTRICTED DATA~~

MAY 29 2015

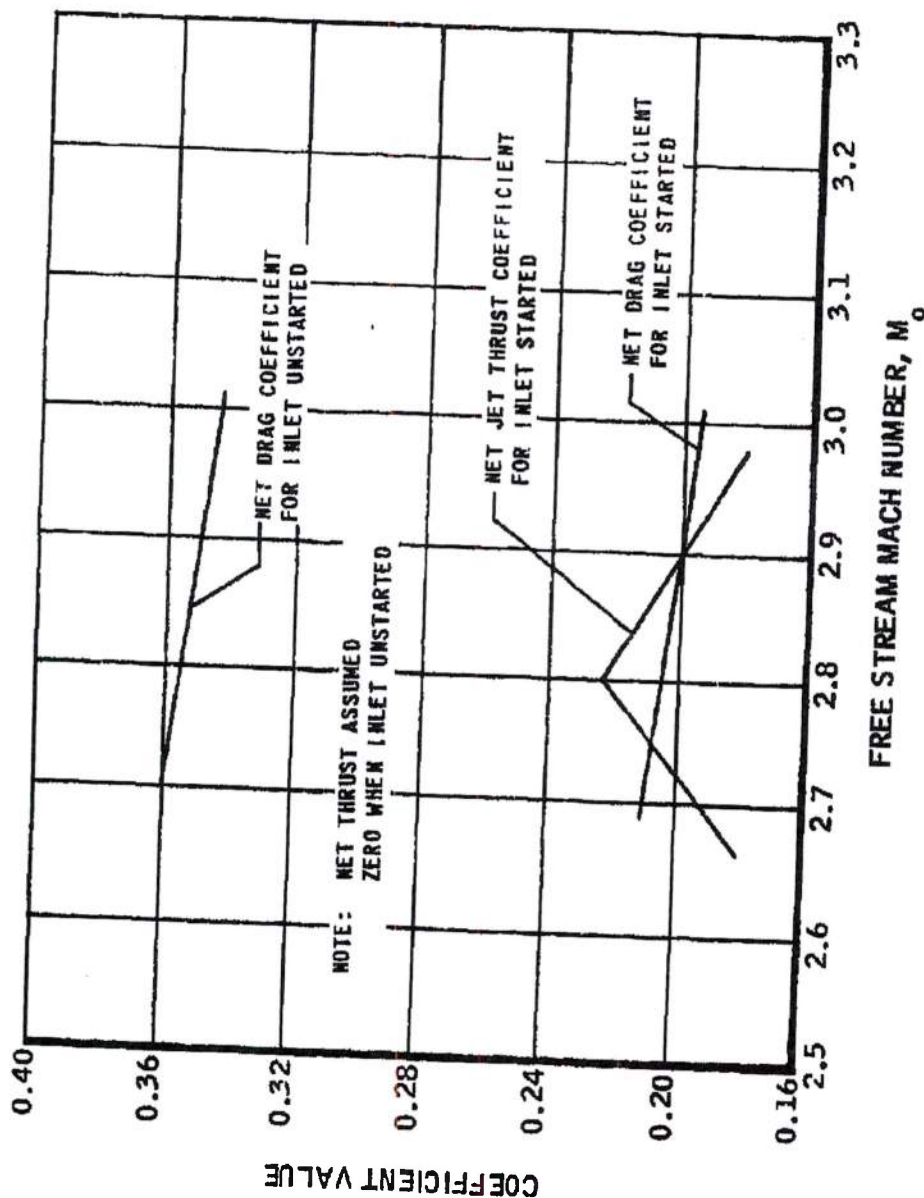
*Marquardt*  
VAN NUYS, CALIFORNIA

~~SECRET RESTRICTED DATA~~

REPORT 58

~~ATOMIC ENERGY ACT OF 1954~~

NET DRAG COEFFICIENT FOR UNSTARTED INLET  
AND NET THRUST AND DRAG COEFFICIENTS FOR STARTED INLET



~~SECRET RESTRICTED DATA~~



~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

accomplished at the higher altitude is significantly lower than Mach 7.5. It is still necessary, when the vehicle is climbing without power, to overcome the effects of the increased drag due to the higher angle of attack and the loss of kinetic energy used for climbing.

The analysis was performed using general linearized three-degrees-of-freedom equations of motion, which represent longitudinal missile motions about the stability axis resulting from perturbations in selected flight conditions (Reference 27). The pitch control and altitude control autopilot equations that were given in the Twenty-Fifth Quarterly Progress Report were used for closed-loop control of the longitudinal airframe dynamics.

The complete set of closed-loop equations were simulated on the analog computer to obtain the transient response of the system.

The net thrust and drag were programmed using the curves in Figure 151. The solution, resulting in Figure 150, was obtained by the following sequence: unstart was simulated by increasing the total drag and reducing thrust to zero; just before the forward velocity reached the lower limit for restart, the inlet was restarted and thrust and drag were taken from the curves for the restarted condition at the new Mach number. It is seen that, even though the inlet is restarted, a long acceleration period is required to reach Mach 2.90 again as the thrust-drag margin is low. Should an unstarted condition arise again before the vehicle could accelerate close to normal speed, the subsequent time for restart would be very short. It is therefore important to establish the possibility of recurrence of the conditions that can initially cause unstart. For a repetitive restart capability, the allowable time for each restart would be approximately  $3.0/N$  seconds where  $N$  is the desired number of restarts.

#### 4.3 CONTROL SYSTEM COMPONENTS

##### 4.3.1 Neutron Flux Sensor

The 1959 and 1960 ion chamber irradiation test programs were designed to investigate the operating characteristics of a high-temperature, compensated ion chamber suitable for Pluto application. The first test program was designed to test the upper operating limits of the prototype design in high neutron and high gamma radiation fields. The second test program was designed to determine the temperature capabilities of the ion chamber. In both tests the ion chambers were operated in the General Electric Materials Testing Reactor (MTR). In the first test series, the ion chamber was operated directly in the core

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~





~~SECRET RESTRICTED DATA~~

REPORT 58

ATOMIC ENERGY ACT OF 1954

in a thermal neutron flux of  $10^{14}$  nv and a gamma dose of  $10^9$  R/hr. In the second test series the ion chamber was operated inside a furnace capsule to simulate operating temperatures up to  $1200^\circ\text{F}$ .

In both of these test series the ion chambers were operated in high thermal neutron flux fields. The ion chamber signal current was primarily due to the  $(n, B^{10}) \rightarrow \alpha, Li$  interaction with the filling gas. Previous study work of Pluto flux spectrum indicated that the ratio of chamber neutron current to gamma current would be high enough that an uncompensated ion chamber could be used for measuring reactor power. However, this condition is true only when the chamber is located directly in the core reflector where the thermal neutron flux is maximized. Any other location would require the use of a moderator to thermalize the neutron flux for detection, or the use of a compensated ion chamber. Either approach would complicate the overall system.

The purpose of the 1961 ion chamber irradiation test program was to investigate methods of improving the gamma current discrimination of the Pluto uncompensated ion chamber. To conduct such an investigation, a reactor was required that had high fast-neutron flux, gamma flux, and low thermal-neutron flux. The reactor selected for this work was the General Dynamics test reactor located in the Nuclear Aerospace Research Facility at General Dynamics/Fort Worth.

For this work, two Pluto-type uncompensated ion chambers were used for the detectors. The first chamber was a standard  $B^{10}$ -coated, neutron ionization chamber. The second chamber was identical but was uncoated. The two ion chambers were manifolded together to a common gas filling and venting system. Nitrogen, argon, xenon, helium, and hydrogen were alternately used as filling gases.

The experiment was so conducted that the saturation characteristics were taken for both the neutron and gamma ion chambers. Saturation curves were obtained for all filling gases at different pressures and at three temperature levels.

Figure 152 is a plot of the current collected in the gamma ion chamber at different operating pressures. It should be noted that the gamma current increased as the density of the filling gas increased.

Figure 153 is a plot of the current collected in the neutron ion chamber. It should be noted that the current collected is actually the sum of the neutron and gamma current of the uncompensated ion chamber. As expected, the ionization current curves increase with pressure, leveling off when the range of the  $(\alpha, Li)$

~~SECRET RESTRICTED DATA~~

ATOMIC ENERGY ACT OF 1954

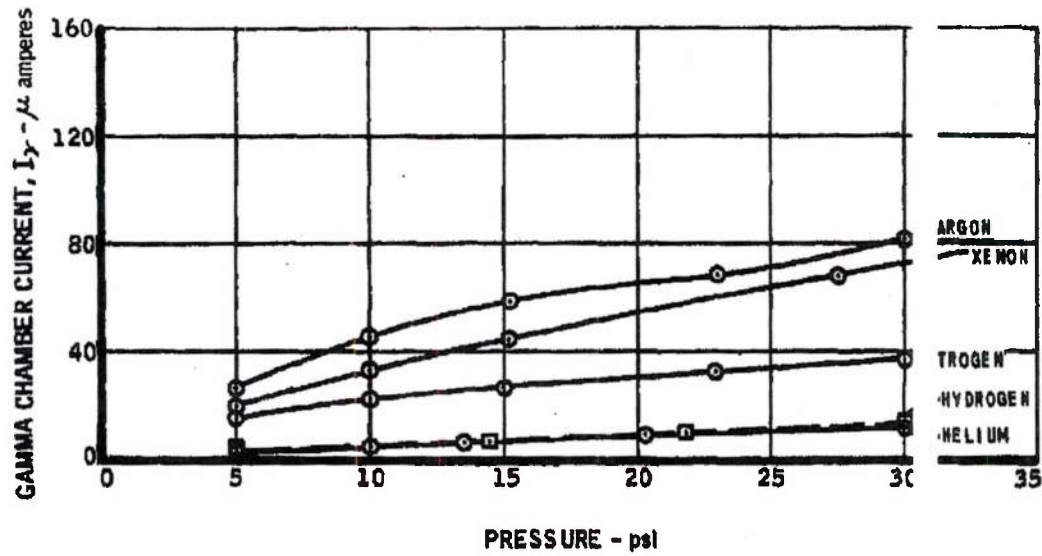
UNCLASSIFIED

*The Marquardt Corporation*  
VAN NUYS, CALIFORNIA

POST 5876

# GAMMA ION CHAMBER CHARACTERISTICS

FILLING GAS TEMPERATURE = 780°F



Page determined to be Unclassified  
Reviewed Chief, RDD, WHS  
IAW EO 13526, Section 3.5  
Date: MAY 29 2015

MAC 1673

22G103 UNCLASSIFIED

-271-

FIGURE 152

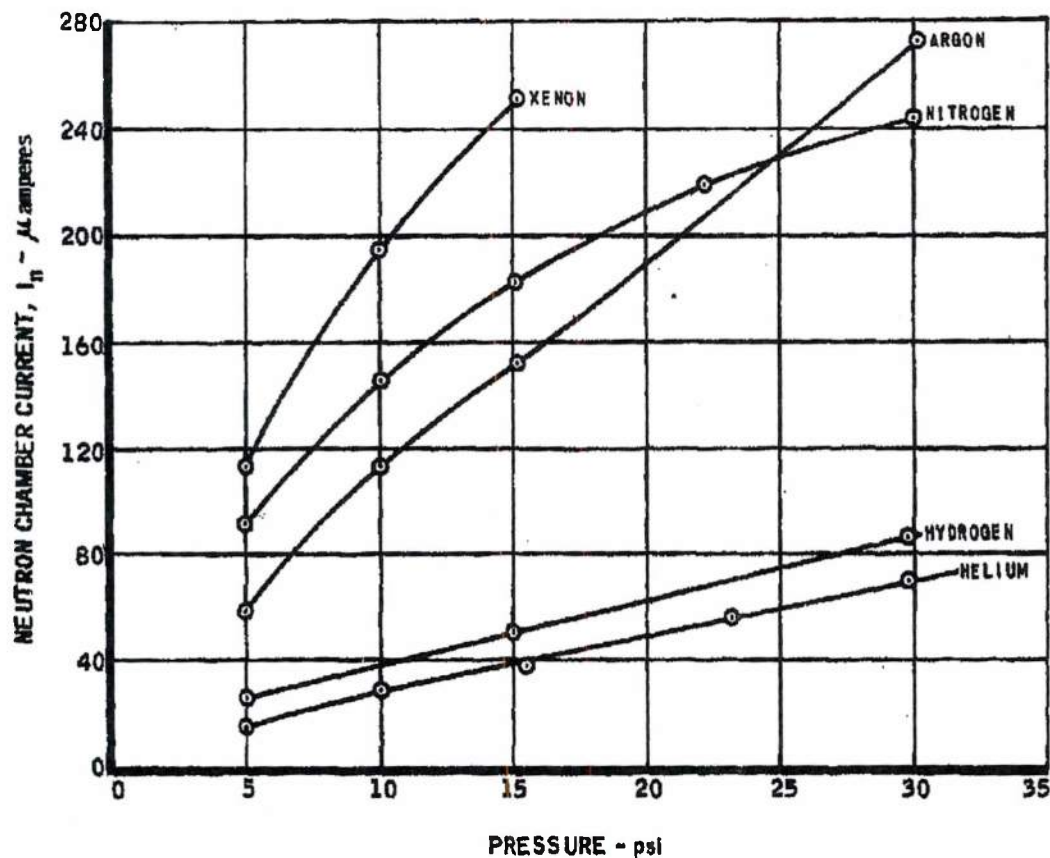
UNCLASSIFIED

*Marquardt*  
CORPORATION  
VAN NUYS, CALIFORNIA

REPORT 58

# NEUTRON ION CHAMBER CHARACTERISTICS

FILLING GAS TEMPERATURE = 780°F



has been determined to be UNCLASSIFIED  
Reviewed Chief, RDD, WHS  
IAW EO 13526, Section 3.5  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

particles resulting from the  $(n, B^{10})$  reaction equal the plate spacing of the ion chamber. Normally, the curves reach a saturation value; however, in this case the gamma current continued to add to the total ionization current as the gas pressure increased.

Figure 154 is a plot of the ratio of ionization current collected from the neutron chamber to the ionization current collected from the gamma chamber for different filling gases. Surprisingly, hydrogen gas proved to have the highest neutron/gamma ratio of all the gases used. This high ratio is apparently caused by the fast neutrons interacting with the hydrogen atoms, ionizing the hydrogen gas directly by collision rather than by the normal thermal neutron  $B^{10}$  reaction. This method of using hydrogen filling gas to decrease the gamma sensitivity of an uncompensated ion chamber is a new idea. It may be very useful for extending the range of uncompensated ion chambers when operating in fast neutron flux environments.

#### 4.3.2 Temperature Sensors

##### Thermocouples

At the beginning of 1961, calibration data, drift, and aging characteristics had been obtained on several metallic thermocouple systems including:

- Platinum vs. platinum - 10 percent rhodium
- Platinum vs. platinum - 5 percent rhodium
- Platinum vs. platinum - 20 percent rhodium
- Platinum - 5 percent rhodium vs. platinum - 20 percent rhodium
- Platinum - 6 percent rhodium vs. platinum - 30 percent rhodium
- Iridium vs. iridium - 40 percent rhodium

Also, there were two combinations of the platinum vs. platinum-rhodium system doped with 1 and 2 percent palladium.

In general, the maximum drift was about 1 to 2 percent. The independent linearity errors for the platinum vs. platinum - 10 percent rhodium thermocouple was about  $\pm 1$  percent in the region of 1000 to 3000°F. All of the systems have larger nonlinear characteristics in the range of 0 to 1000°F.

An analytical study of thermocouple circuits was conducted and the effects of circuit resistance in the connecting system were predicted and experimentally verified. Series and parallel thermocouple operation was investigated, and it was shown that the terminal voltage of a series network was multiplied by

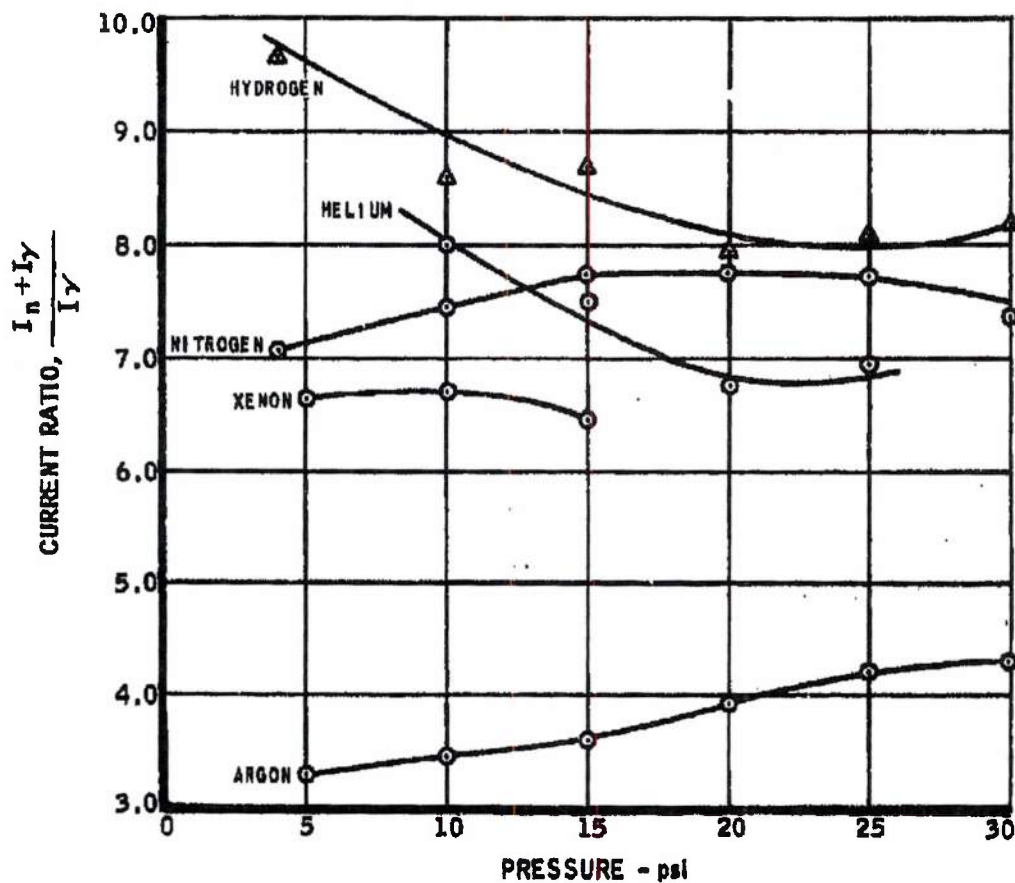
~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~



## NEUTRON CHAMBER - GAMMA CHAMBER CURRENT RATIO

FILLING GAS TEMPERATURE = 780°F



Page determined to be Unclassified  
Reviewed Chief, RDD, WHS  
IAW EO 13526, Section 3.5  
Date:

MAY 29 2015

~~SECRET RESTRICTED DATA~~

*Marquardt*  
VAN NUTS, CALIFORNIA

ORT 5876

~~ATOMIC ENERGY ACT OF 1954~~

the number of series junctions but reduced by the effect of the series and parallel resistance in the circuit. In parallel operation, the terminal voltage was the same as in the case of the single junction, reduced slightly by the effect of circuit resistances. Tests were also conducted on some metallic thermocouples (tungsten rod vs. a graphite sheath). The results indicated a large but nonlinear voltage output with temperature, and a large number of thermocouple failures after one 10-hour run of several thermocouples. It was concluded that poor electrical reliability, relatively large size, and lack of mechanical durability made this type of thermocouple unsuitable for the required applications of in-core temperature instrumentation.

Thermocouple insulators were experimentally investigated. A part of the thermocouple tests and insulation resistance between two wires in the two-hole insulators was measured as a function of temperature up to 2800°F for alumina and magnesia. Insulation resistance of the alumina was slightly higher than the magnesia at 2800°F, and was about 40,000 ohms at this temperature. Reference 28 contains the extensive temperature test results of the various thermocouple systems, insulators, resistance-type temperature sensors, and bridge circuits.

In late 1960 and early 1961, a thermocouple irradiation experiment was performed in which platinum vs. platinum - 10 percent rhodium thermocouples at 2500°F were irradiated to a total integrated fast neutron dose of about  $6 \times 10^{19}$  nvt and a total integrated thermal-neutron dose of about  $1.6 \times 10^{20}$  nvt. In addition, a platinum vs. platinum - 10 percent rhodium thermocouple and a chromel-alumel thermocouple in an environment of about 1400°F were irradiated in the same test capsule. The insulation resistance of a two-hole alumina thermocouple insulator was also measured. Reference 29 contains a complete description of the pre-radiation, radiation, and post-radiation test conducted in 1961. In general, the results indicated that the maximum permanent decalibration of the platinum vs. platinum - 10 percent rhodium thermocouples was about 0.8 percent at an operating temperature of 2500°F and a maximum integrated flux of  $6 \times 10^{19}$  nvt fast neutrons and  $1.6 \times 10^{20}$  nvt thermal neutrons. The data also indicated essentially constant insulation resistance for the same operating temperature and values of integrated flux. In order to isolate any thermal aging effects that may have occurred during the 500-hour irradiation test at 2500°F, a 500-hour aging test was performed using thermocouples fabricated from the same batch of wire as that used in the irradiation tests.

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

~~SECRET RESTRICTED DATA~~

*The Marquardt*  
CORPORATION  
VAN NUYS, CALIFORNIA

REPORT 58

~~ATOMIC ENERGY ACT OF 1954~~

The results of this test indicated a thermal drift of 1° F at the end of 500 hours of operation.

#### Resistance-Type Temperature Sensors

At the beginning of 1961, a survey of commercially available resistance-type temperature sensors had indicated that no sensors of this type were commercially available for operation to 3000° F. In addition, an analytical study had been completed to predict the extent of strain gage effects, and experimental work had been started on platinum wire resistance units. The analytical study showed that the magnitude of these strain gage effects was small and negligible, and the preliminary experimental work indicated that the insulation resistance characteristic of the winding form was a significant factor in affecting the linearity of these devices at temperatures above 2000° F.

During 1961, both platinum, iridium, and tungsten wire resistance elements were calibrated using various winding geometries and forms. The tungsten sensors were calibrated in inert and vacuum environments. The repeatability with temperature cycling of the platinum wire sensors was significantly better than that of the tungsten units.

A special winding form constructed to minimize the insulation resistance shunting effect on the sensor, in conjunction with a total platinum wire resistance of about 27 ohms at 2800° F, produced the most successful results to date. Figure 155 is the calibration curve of this experimental platinum wire resistance sensor from ambient to 2800° F. This device has an independent linearity error of about ±3 percent over the entire temperature range.

#### 4.3.3 Pneumatic Control Components

At the beginning of the contract year, the 4-inch-stroke actuator system had been completely designed and fabricated, and the unit was ready for testing. The design of the 40-inch-stroke actuator was complete, and fabrication had been initiated. Design of the test equipment for use in evaluating the actuators had commenced.

During 1961, significant progress in perfecting high-temperature, pneumatic components was achieved. The 4-inch-stroke actuator system was completely evaluated and the evaluation provided data for design improvements in future actuators. Fabrication of the 40-inch-stroke actuator was completed.

DECLASSIFIED IN FULL

Authority: EO 13526

Chief, Records & Declass Div, WHS

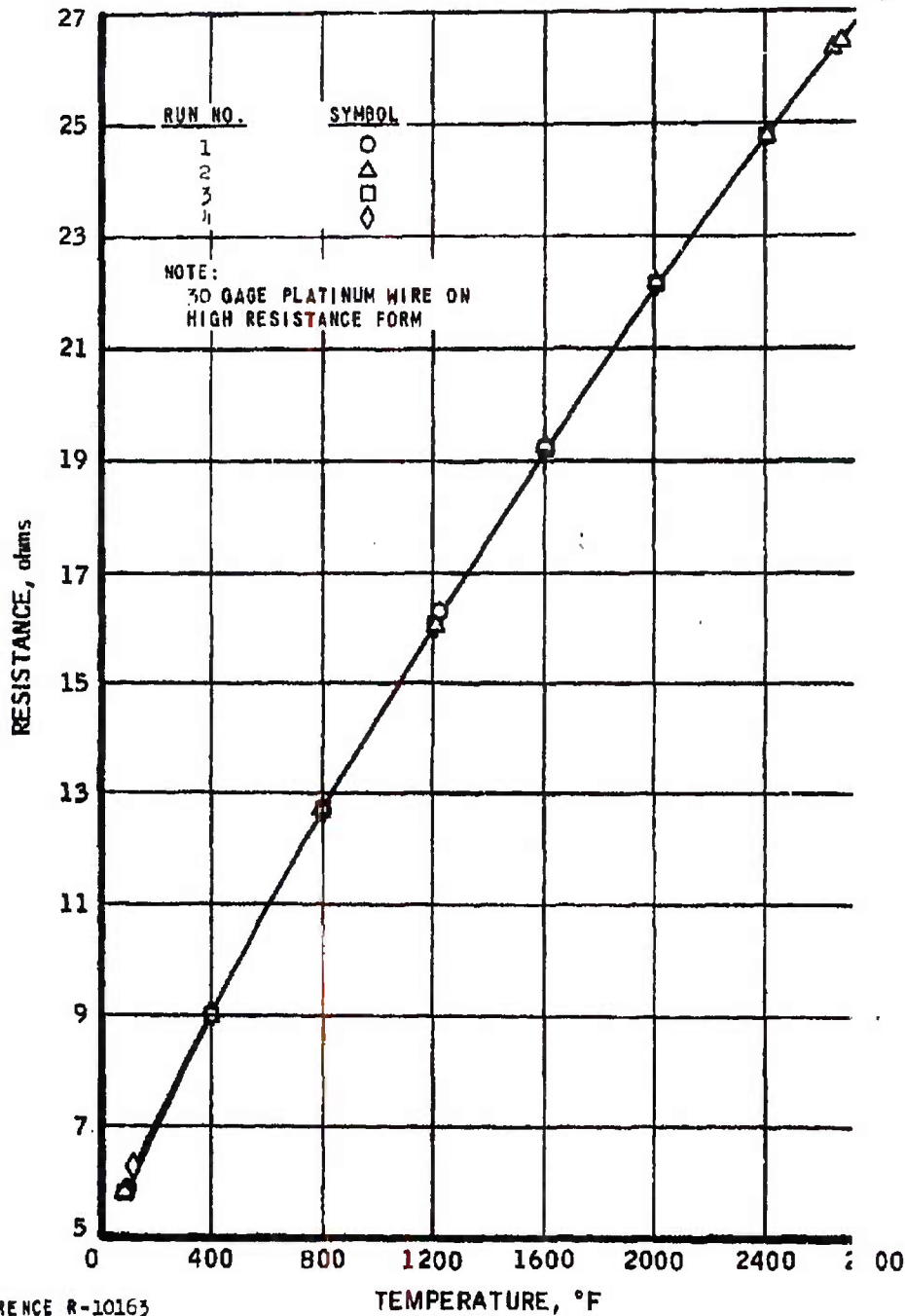
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

UNCLASSIFIED

# CALIBRATION OF EXPERIMENTAL PLATINUM WIRE RESISTANCE SENSORS



REFERENCE R-10163

MAC AGS

22G144 UNCLASSIFIED

-277-

FIGURE 155



DECLASSIFIED IN FULL

Authority: EO 13526

Chief, Records & Declass Div, WHS

Date: MAY 29 2015

*Marquardt*  
VAN NUYS, CALIFORNIA

~~SECRET RESTRICTED DATA~~

REPORT 58

ATOMIC ENERGY ACT OF 1954

and extensive testing at both room temperature and 1000° F resolved many problems and resulted in dynamic performance for short periods compatible with flight requirements. A research program covering high-temperature materials and lubrication was initiated under which a survey of the state-of-the-art of high-temperature lubricants was completed, screening of the most promising lubricants and materials accomplished, and testing initiated.

#### Four-Inch-Stroke Actuator

Performance testing of the 4-inch-stroke actuator was completed, and the program objective of optimizing system performance utilizing existing hardware was achieved. The actuator shown installed in its environmental oven (Figure 156) was operated at room temperature for 40 hours. Two successful one-hour tests were conducted at 1000° F.

Frequency response, resolution, and transient response characteristics of the actuator were evaluated during ambient and high-temperature phases of the tests. The poor resolution obtained (3.5 percent at room temperature and 4 percent at 1000° F) was the result of earlier extensive high-temperature testing of the motor. This testing resulted in larger dead band than specified in the design.

Transient response data showed that actuator performance was well within design specifications. Use of a lead-lag network reduced the overshoot and settling time during closed-loop testing without affecting cutoff frequency response. The overshoot was 12 percent of the input as compared to the maximum specified value of 20 percent.

The frequency response data (Figures 157 and 158) show the 90° phase shift point for the room temperature test to be 4.3 cps, and for the 1000° F test, 3.8 cps. These test data correlate closely with the values specified by the analytical actuator studies.

The accumulated test data show good correlation with the predicated performance and provide information valuable to the prediction of future actuator performance.

#### Forty-Inch-Stroke Actuator

Fabrication of the 40-inch-stroke actuator shown in Figure 159 was completed, and extensive room temperature and high-temperature testing of components and of the complete system was accomplished.

~~SECRET RESTRICTED DATA~~

ATOMIC ENERGY ACT OF 1954

UNCLASSIFIED

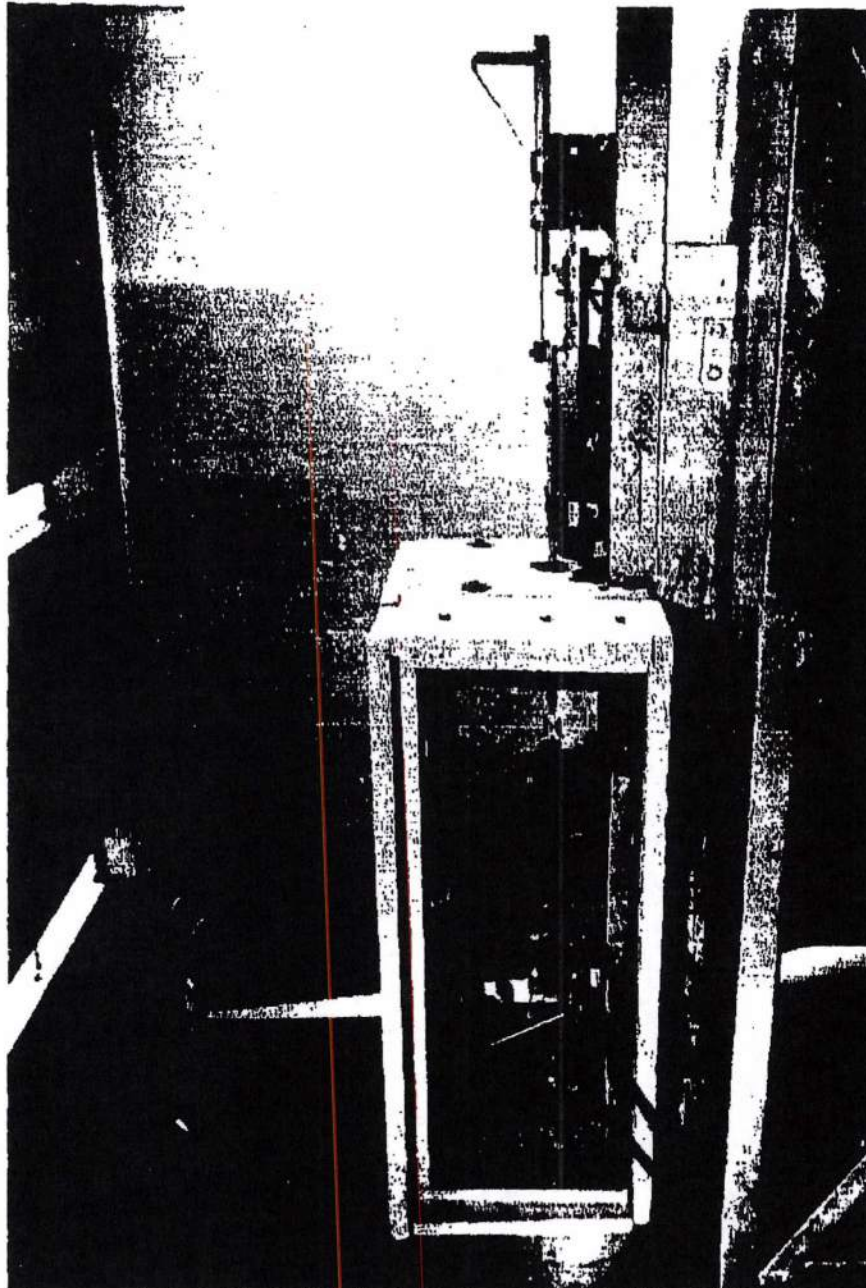


FIGURE 156 - Four-Inch-Stroke Actuator Installed in  
Environmental Oven

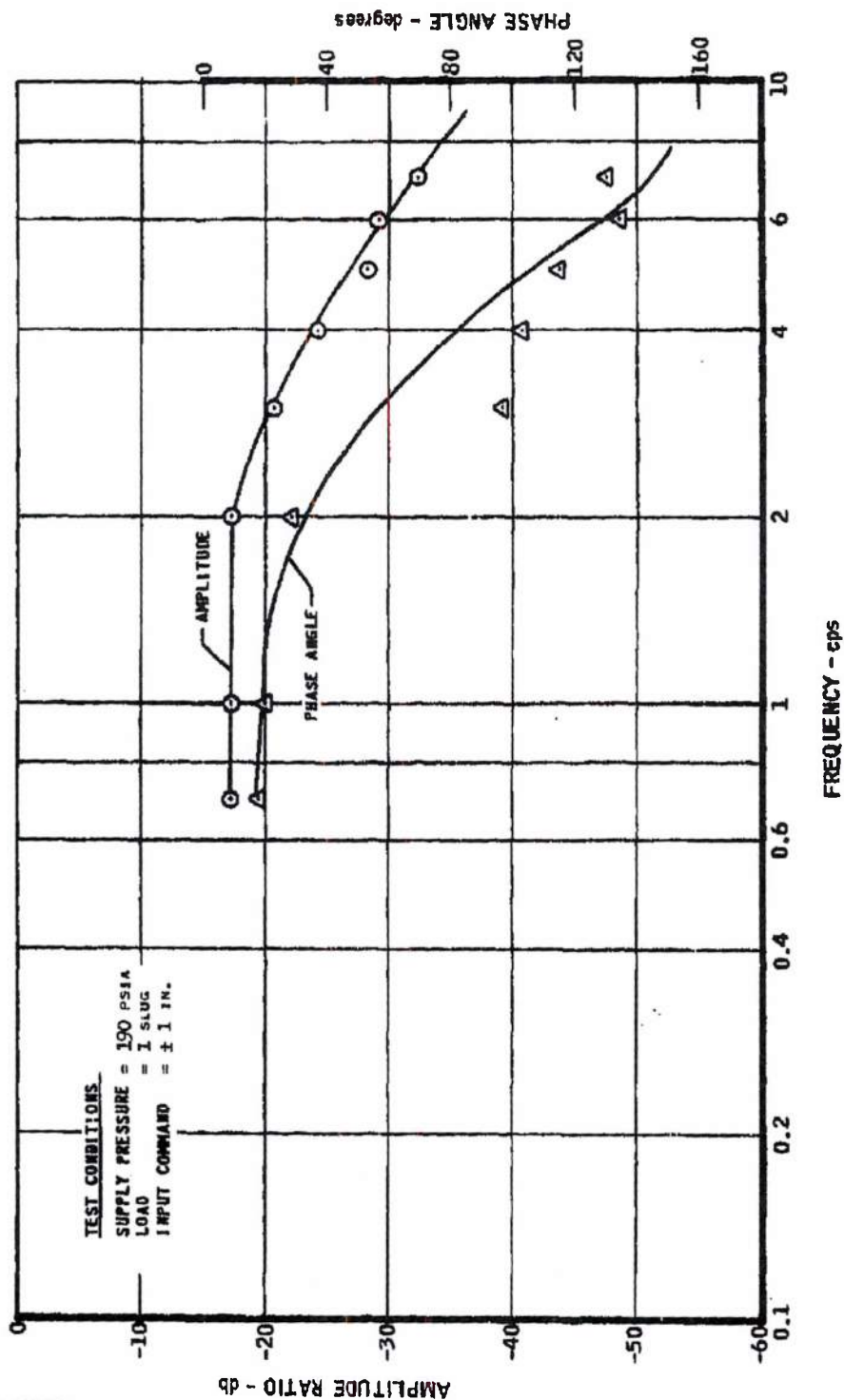
3772-3CN

MAC A03

UNCLASSIFIED

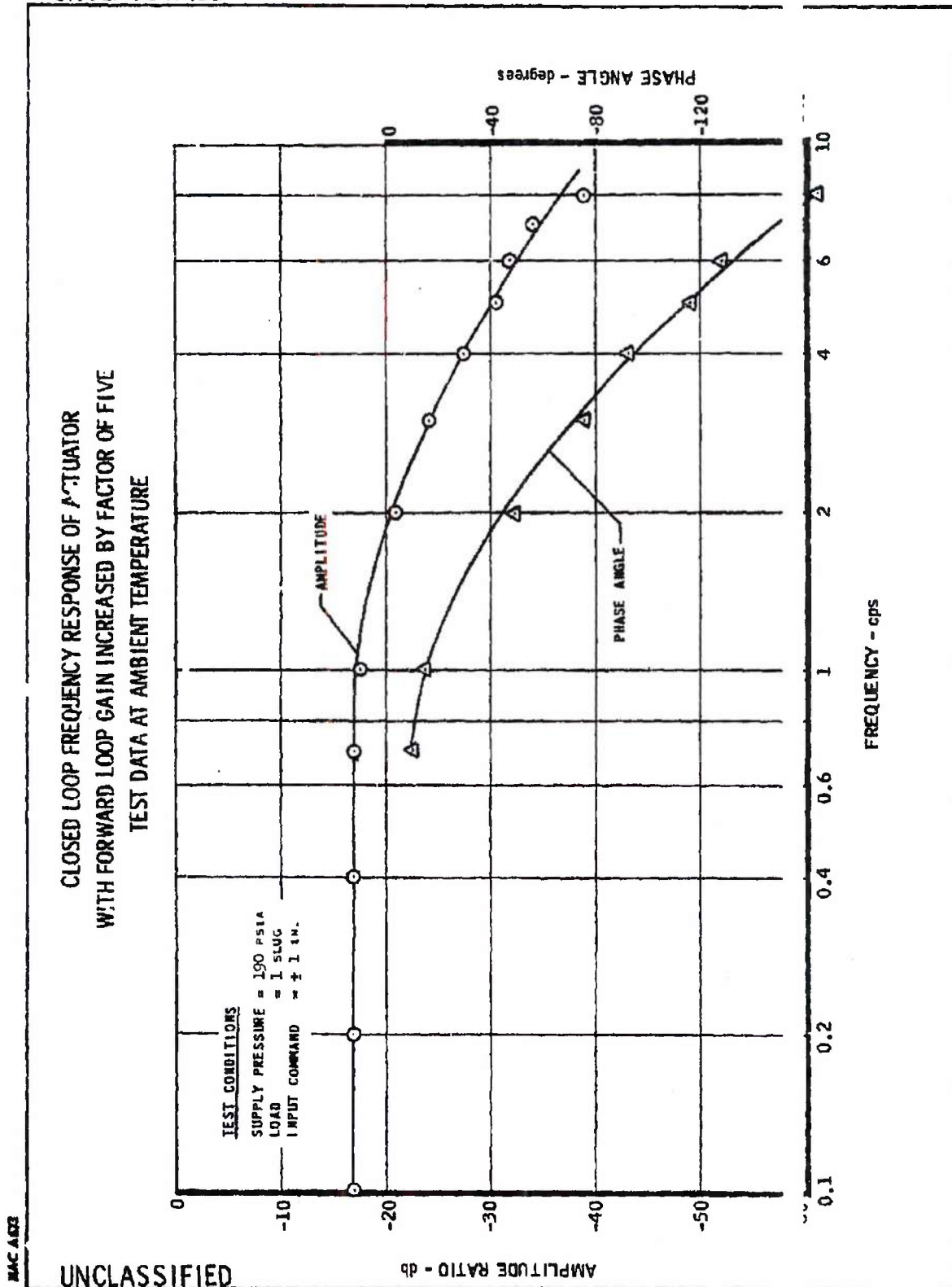
UNCLASSIFIED

CLOSED LOOP FREQUENCY RESPONSE OF ACTUATOR  
 WITH FORWARD LOOP GAIN INCREASED BY FACTOR OF FIVE  
 TEST DATA AT 1070° F



UNCLASSIFIED





MAC 483

22G57

-281-

FIGURE 158



UNCLASSIFIED

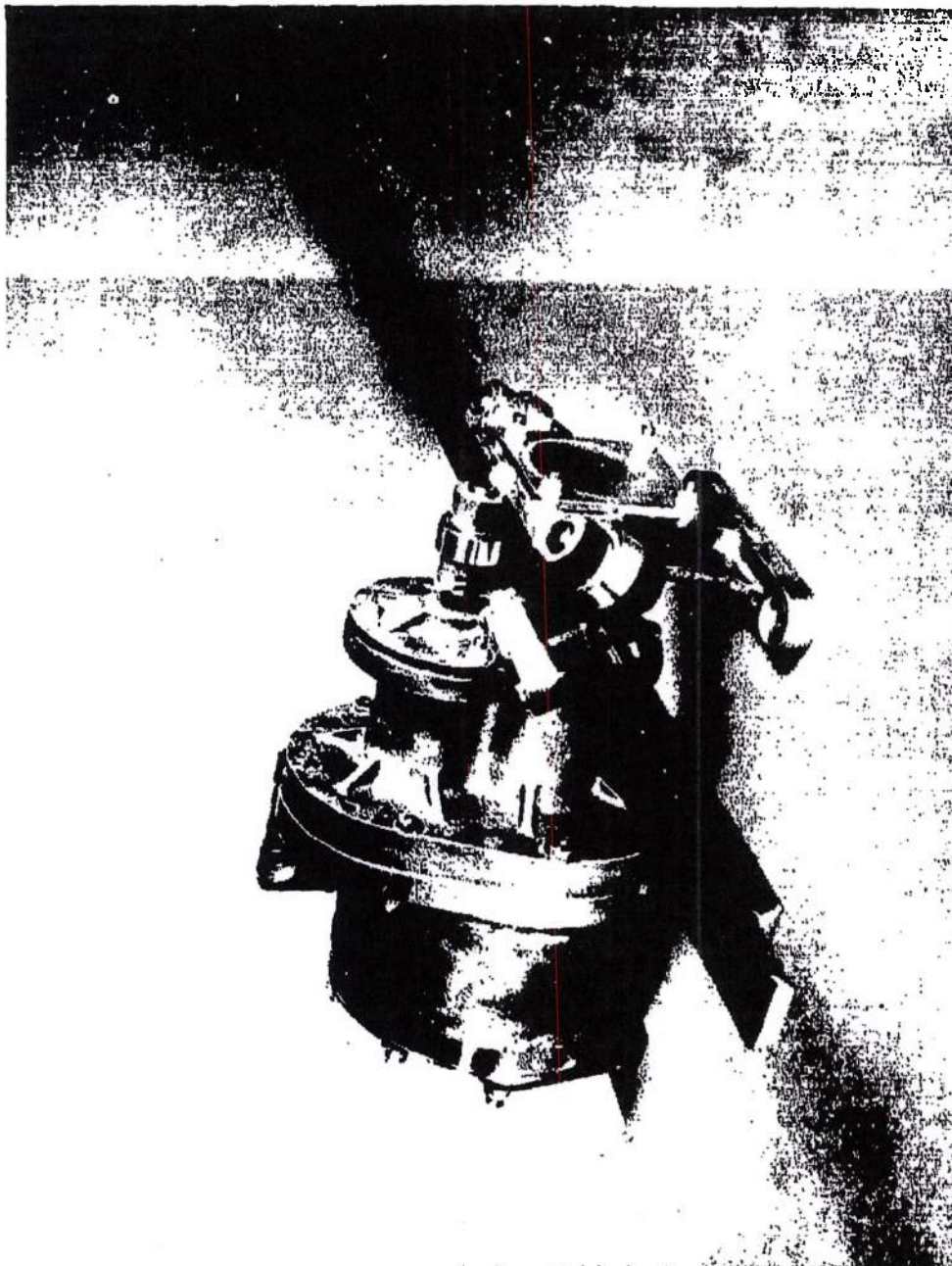


FIGURE 137 - FORTY-HIGH-STROKE ACTUATOR

3751-4CN

UNCLASSIFIED

*The Marquardt*  
VAN NUYS, CALIFORNIA

PORT 5876

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

Component testing consisted of evaluation of two types of linear transducers (a linear variable differential transformer and a variable reluctance type), the first and second stage valves, and the nutating disk motor.

The transducer evaluation included testing of both types at room temperature and at 1000° F to determine their linearity and repeatability characteristics. It was determined that the linear variable differential transformer in combination with its oscillator and demodulator exhibited poor linearity and repeatability at both room and 1000° F temperatures. The variable reluctance transducer met the specified requirements for both linearity and repeatability at both temperature conditions and was used in subsequent system tests of the complete actuator assembly.

Bench testing of the motor indicated that leakage and friction were within design limits; however, severe inertial knock occurred between the nutating disk and the splitter plate during operating. As a result the splitter plate was eliminated, and a pin and shoe arrangement was installed at the periphery of the disk to balance out the inertial forces arising from the nutating motion.

Motor operation was much improved by this modification, but repeated failures of the pin pointed up the need for design refinements to reduce the stress concentration at the pin. Appropriate design changes have been made which will be incorporated in all future actuator motors.

Bench testing of the valve, which consisted of a torque motor and first and second stage spool valves, indicated a number of problems, which were resolved in the following manner. Static sensitivity of the valve was found to be poor, and the feed back gain of the second stage was modified to eliminate this problem. The first stage gain was found to be inadequate. However, to circumvent the delay associated with redesign and fabrication, the first stage valve from the 4-inch-stroke actuator was substituted, because its performance was found to be satisfactory. Repeated malfunctions of the second stage valve were encountered. When it was determined that malfunction was caused by spool binding in the sleeve, the clearance between the spool and the sleeve was increased. It was also found that valve performance was being severely limited by excessive dead band in the torque motor. Because the only two torque motors available for the high-temperature operation had similar characteristics, it was necessary to minimize dead band effects through the use of electronic compensation in the forward loop of the servo system.

MAC 403

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

Initial tests of the actuator were conducted at room temperature, a resolution, transient response, and frequency response tests were performed to determine the actuator's dynamic capabilities. Approximately 60 hours of operating time were accumulated during this testing. Frequency response was found to be 4 1/2 cycles without compensation and 8 to 10 cycles using proportional plus integral and lead-lag networks. Resolution was one tenth of 1 percent (Figure 160), and transient response (Figure 161) showed overshoot as a maximum of 20 percent. Actuator performance was limited due to low gain and dead band in the torque motor. However, operation of the actuator at inlet pressures (40 psi) demonstrated its ability to operate at pressures comparable with those to be encountered in the inlet duct of the Pluto engine at high altitudes.

Checkout of the environmental oven used to conduct high-temperature testing was completed, and the actuator was installed. The initial high-temperature test of the actuator was of half-hour duration at 1000° F. Actuator operation was achieved at this temperature; however, problems were encountered in the clutch that is used to shift from the servo to the scram mode of operation. Clutch malfunction was due to the use of ambient air to operate the clutch while the actuator was at the 1000° F test temperature. This problem was eliminated by installing coils in the environmental oven so that the clutch air is heated before entering the actuator. This solution has proved satisfactory.

The second high-temperature run of the actuator assembly was of 1 hour duration at 1000° F. Operation of the actuator was satisfactory, and dynamic performance was comparable to that exhibited during the low-temperature testing. Reworking of the valve successfully eliminated mechanical binding problems that occurred during initial tests. Additional valve evaluation will be required to eliminate dead band and improve dynamic performance.

#### High-Temperature Materials and Lubrication Research

In the course of the Marquardt effort to develop 1200° servo actuating equipment, it became increasingly obvious that the lack of documented information on the friction and wear characteristics of materials at elevated temperatures was hindering development progress. During 1961, a two-phase program was initiated in the hope of alleviating this problem.

The first phase consisted of a literature survey involving intensive search study and abstracting to determine the state-of-the-art. In addition, visits were made to all companies and research agencies prominent in the field

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

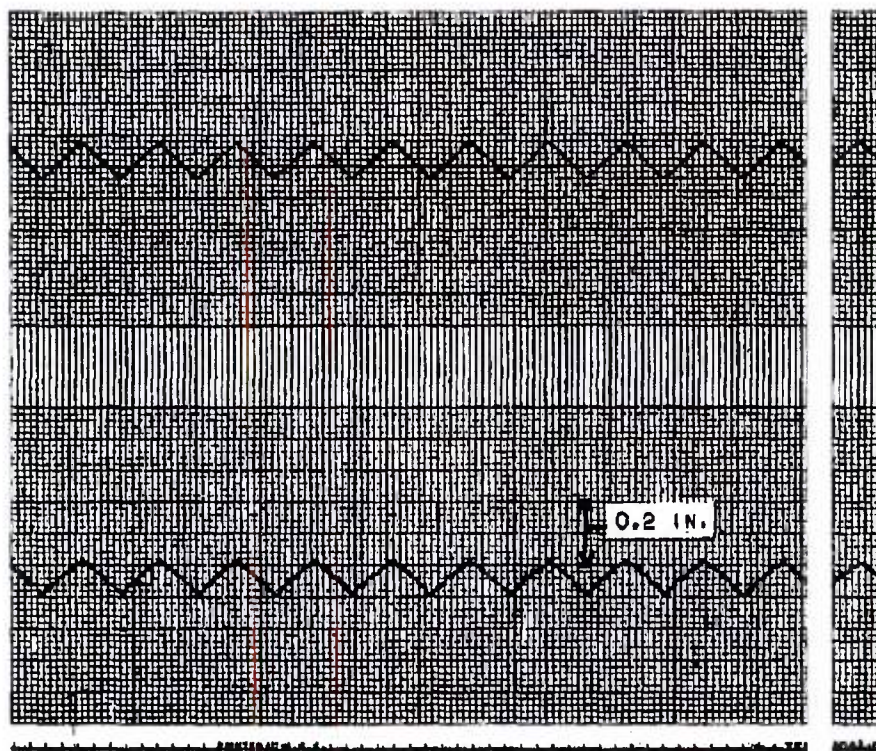


UNCLASSIFIED

*The Marquardt*  
Instruments  
VAN NUYS, CALIFORNIA

PORT 5876

## RESOLUTION OF FORTY-INCH-STROKE ACTUATOR



$$P_s = 40 \text{ psi}$$

$$T_s = T_A = 70^\circ \text{F}$$

Page determined to be Unclassified  
Reviewed Chief, RDD, WHS  
IAW EO 13526, Section 3.5  
Date: MAY 29 2015

MAC 1453

UNCLASSIFIED

22G145

-285-

FIGURE 160

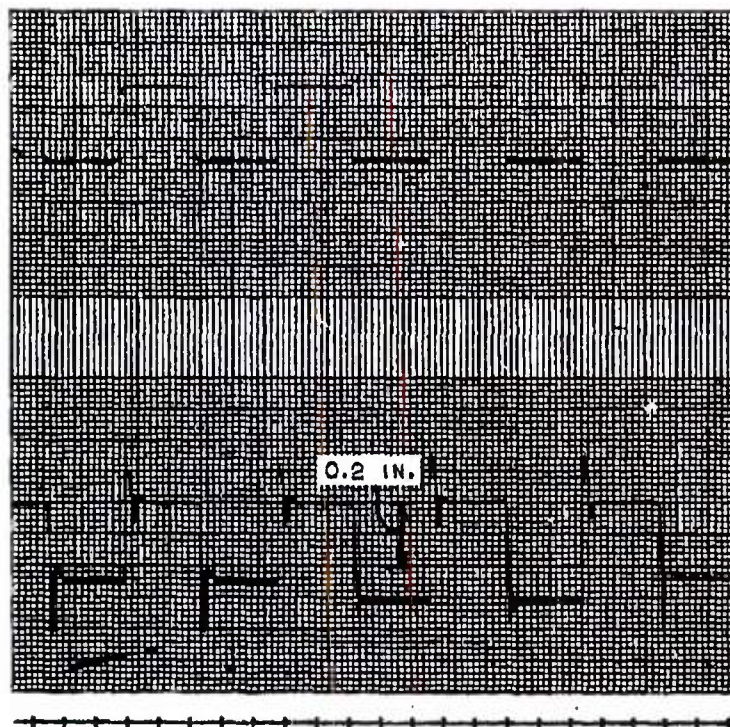


UNCLASSIFIED

THE *Marquardt*  
CORPORATION  
VAN NUYS, CALIFORNIA

REPORT 587

## TRANSIENT RESPONSE OF FORTY-INCH-STROKE ACTUATOR



$$P_s = 150 \text{ psi}$$

$$T_s = T_A = 70^\circ\text{F}$$

Page Unclassified to an unclassified  
Reviewed Chief, RDD, WHS  
IAW EO 13526, Section 3.5  
Date: MAY 29 2015

UNCLASSIFIED

22G147

-286-

FIGURE 161

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

of high-temperature materials and lubricant research. As a result of these surveys, it was concluded that there are four basic approaches to the high-temperature lubrication problem that are particularly applicable to the Pluto system: a dry film lubricant, a solid lubricant compact, a continuous or intermittent-flow dry lubricant system, and a pneumostatic bearing.

A Dry Film Lubricant applied to the bearing surface is the simplest from a hardware design standpoint. However, the three basic problems of securing adequate adhesion, long wear life, and good lubrication at high and low temperatures may not be amenable to timely solution.

The following list of candidate dry film lubricants and wear coatings came out of the survey:

- (1) Lead with silica (NASA lubricant coating)
- (2) Other low melting point glasses with or without additive (Midwest Research, Massachusetts Institute of Technology, University of Illinois, and Aeronautical System Division a lubricant coating)
- (3) Flame sprayed cermets and ceramincs (Linde-a wear coating)
- (4) Conversion coatings, such as oxides, silicones or chromes (wear coatings)
- (5) Precious metal coatings (Southwest-a lubricant coating)
- (6) Proprietary coatings (Columbia Broadcasting System Research Laboratories, Alpha Molykote, Electrofilm, General Motors Plate, Stratos, "Surf-Kote"-lubricant coatings)

In the case of a self-generating oxide coating (current Marquardt approach) used for its anti-wear properties, some benefit might be gained by maintaining a more uniform oxide coating. The Boeing Company, Franklin Institute, and General Electric Corporation have accomplished considerable research engineering on pneumatic bearings applicable to this type of problem.

Solid Lubricant Compact applied against bearing wear surfaces is more complex from a mechanical standpoint, but provides "lubrication in depth" resulting in longer life. The "compact" can be applied by using inserts that rub against the bearing components or by using spacer balls or spacer rollers formed from a lubricant compact.

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date:

MAY 29 2015

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

Graphites, self-oxidizing mixtures, laminar layer solid lubricants, and precious metals are being considered as the lubricating element. Boeing, Clevite, National Carbon, NASA, NAMC, and others have been working on this principle. In general, wear rates of the compact are high, in order to keep a good lubricant supply available, so the compact itself cannot be dimensionally critical.

A Continuous- or Intermittent-Flow Dry Lubricant System using a carrier gas is the most mechanically complex, but holds the greatest potential for long life and heavy duty. The selection of lubricant materials should not be critical because of the continuous replenishment feature.

Metering of the lubricants and their injection into the airflow would be the primary problem. The advantages are that (1) molybdenum disulfide and other excellent dry lubricants can be used, and (2) the continuous replacement and greater uniformity of distribution should allow an extremely long wear life comparable to conventional hydrocarbons used at lower temperatures.

A Pneumostatic Bearing would be less complex than a solid lubricant compact, but probably more so than a dry film. However, it could be used only if a higher pressure gas source than ram-air were made available.

Within the present state-of-the-art, some type of lubricant is definitely required to reduce friction and wear. Low friction coefficients are desirable to improve performance characteristics of the control system, and wear rate must be minimized to keep operating tolerances within allowable limits.

Hydrostatic gas bearings are possible only if a flowing gas source is available at pressure levels of about four times the maximum bearing pressure load. Little or no hydrodynamic lift can be expected from the oscillating action of the current Marquardt motors consisting of a ball and disk. This design does not lend itself to use of hydrodynamic lift principles because bearing contact area would have to be sacrificed to obtain hydrostatic support area.

The choice of substrate materials presents a much reduced problem when lubricants are used, unless the lubricant is a conversion coating. In this case the substrate must be selected for the desired chemical reaction. Normally the substrate material must be chosen with consideration of the following properties:

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~



~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

- (1) Maximum hot hardness for load carrying capacity
- (2) Dimensional stability from solid state reactions and relaxation of internal stresses
- (3) Good ductility and impact resistance
- (4) Good thermal conductivity to minimize frictional hot spots
- (5) Good oxidation resistance to maintain surface finish and dimensions
- (6) A modulus of elasticity of 25,000,000 to 35,000,000 p.s.i. for optimum contact area
- (7) Machineability

Some of the more promising substrate materials are (1) Haynes 230, (2) Hastelloy "C", (3) Hastelloy "X", (4) Rene' 41, (5) Nitrotung. In general, these cermetts possess superior hardness to the wrought super alloys but have inferior impact resistance, and are difficult to machine. The wrought super alloys should be superior in overall performance for temperatures up to 1500° F. However, as mentioned before, cermetts show some promise as wear coat at the lower temperatures.

The second phase of the materials and lubricant research program consisted of further screening of candidate high-temperature substrate materials and lubricants and correlating literature findings with Marquardt data. This portion of the work was conducted on the Marquardt-designed pin and disk type friction and wear test machine, which is patterned after the successful NASA equipment. At present five test plates and fourteen pins of successful substrate materials are being tested. In addition, six selected lubricant coatings of a propriety nature are being obtained for evaluation.

The objective of this program is to find the best combination of substrate material and lubricant coating for the flight prototype servomotor actuator for the Pluto control system.

#### 4.3.4 Electronics

At the beginning of 1961, most of the magnetic amplifiers and computing devices suitable for use in the temperature and reactor compensation loops had been fabricated, and limited test data had been obtained. Figure 2, which is a simplified block diagram of the temperature control and reactor compensation loops, is included for clarification. These components included a high gain temperature error amplifier, operational type amplifier, a three decade diode-network-type log amplifier, buffer amplifiers suitable for summing and general amplification, and a driver amplifier designed to drive the high-torque motors used in the 40-inch linear actuator system. Methods for providing the required integration in the common error path and methods for mech-

MAC 653

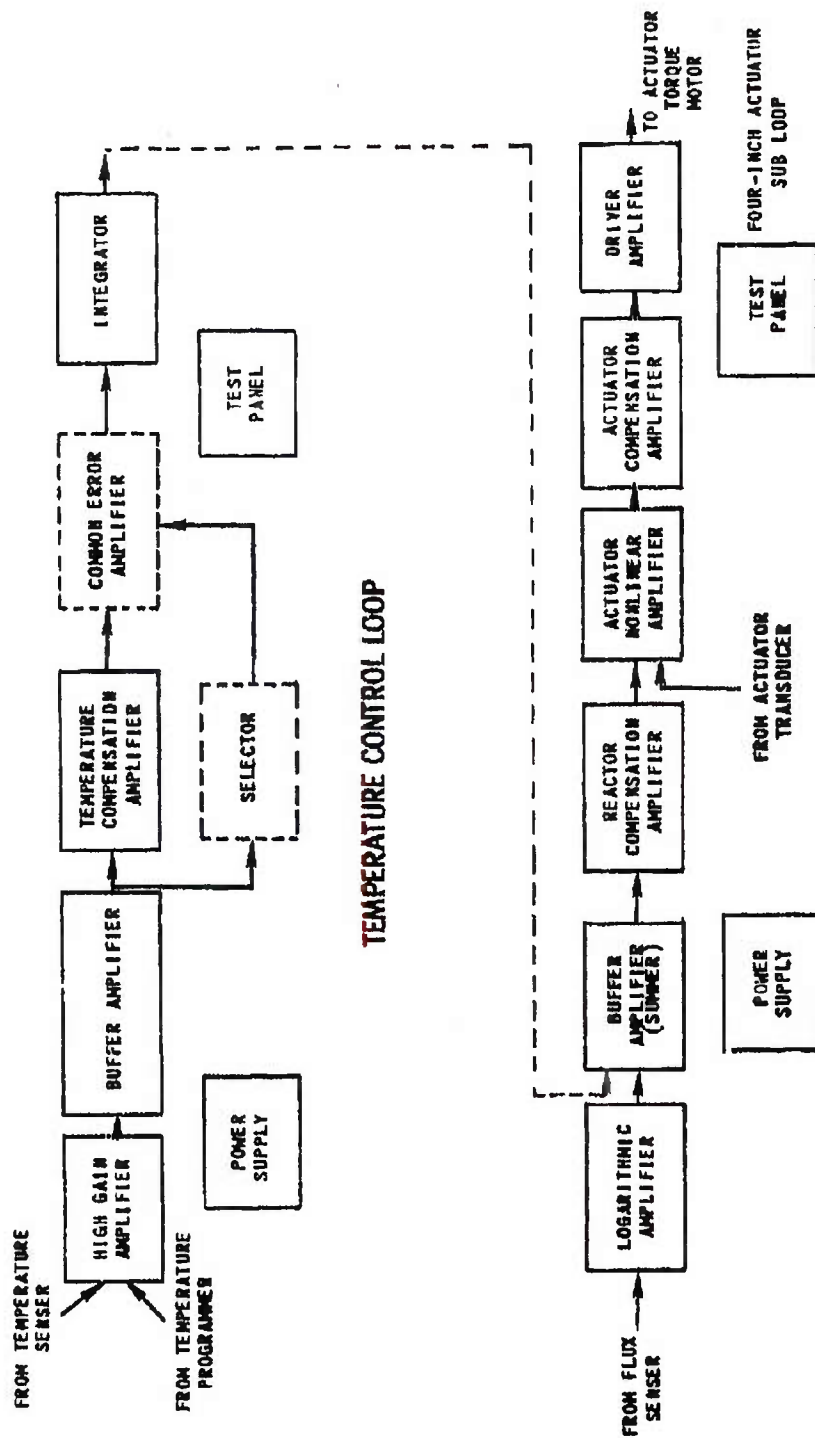
~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~



UNCLASSIFIED

# EXPERIMENTAL TEMPERATURE CONTROL AND REACTOR COMPENSATION LOOPS



## REACTOR COMPENSATION LOOP

UNCLASSIFIED

~~SECRET RESTRICTED DATA~~

ATOMIC ENERGY ACT OF 1954

anization of the auctioneer or error selector were being considere

During the first half of 1961, development tests of the above mentioned components continued, the development of an electronic integrator incorporating magnetic amplifiers was started, and the error selector was subcontracted to an outside vendor for procurement. This contract was subsequently terminated for nonperformance. Selected components and magnetic amplifier circuits were prepared for irradiation tests at General Dynamics/Fort Worth. The magnetic amplifiers were designed to meet the requirements of the control system and were fabricated, tested, and shipped to Fort Worth. These amplifiers included a 400-cps high-gain second harmonic type, and 400-cps and 1800-cps push-pull self-saturating type amplifiers. The second harmonic amplifier is suitable for the first stage of the temperature error amplifier and the integrator. The push-pull self-saturating type represents the buffer amplifier configuration. Components irradiated along with the amplifiers included cores, capacitors, resistors, and diodes of the same type as used in the amplifiers. All of the amplifiers used special, radiation-resistant ZJ225 General Electric diodes of thin base width construction. The remaining amplifiers used standard type silicon junction diodes.

A preliminary report (Reference 30), containing pertinent test results of the August irradiation tests was published in August 1961. In general, the circuits containing the ZJ225 diodes withstood greater radiation exposure for a given performance index than the circuits that contained the ordinary diodes. One 1800-cps amplifier using ZJ225 diodes remained satisfactory after an integrated fast neutron dose of  $2 \times 10^{15}$  nvt. This radiation dose is greater than the dose expected for the electronic system during a typical Pluto mission. The ZJ225 diodes performed satisfactorily to  $10^{16}$  nvt, and five diodes were good to about  $10^{15}$  nvt; however, about 70 percent of the ZJ225 diodes exhibited excessive reverse leakage currents as high as 400 microamperes at 200 volts, which significantly exceeded the anticipated 50 microamperes. Preliminary discussions with the supplier indicated that variations in manufacture occurred and that the excessive leakage was probably a surface leakage phenomenon. All of the components tested except the semiconductors exhibited small or negligible changes in their characteristics to  $10^{16}$  nvt.

During the second half of 1961, the amplifiers and computing components, including the log amplifier and an electronic integrator using magnetic amplifiers, were satisfactorily tested at temperatures from ambient to  $15^{\circ}\text{F}$ . The driver amplifier was exhaustively tested and used in the 40-inch shock actuator development tests. Preliminary tests have been started on the cascaded units in the temperature and reactor compensation loops, and an error selector feasibility design has been completed.

~~SECRET RESTRICTED DATA~~

ATOMIC ENERGY ACT OF 1954

~~SECRET RESTRICTED DATA~~

*The Marquardt Corporation*  
VAN NUYS, CALIFORNIA

REPORT 5876

~~ATOMIC ENERGY ACT OF 1954~~

Second generation 400-cps high-gain and 4800-cps buffer type amplifiers have been designed, fabricated, and preirradiation tested using the information acquired from the August tests.

The development tests of these second generation circuits included comprehensive simulated diode degradation tests in which the forward voltage drop and the reverse leakage current of the diodes was increased beyond the expected values at  $10^{15}$  nvt. A circuit description, performance characteristics, and effects of simulated diode radiation damage on these second generation circuits are presented here.

### Circuit Description

#### (1) Second Harmonic Modulator Rectifier Amplifier

A DC magnetic amplifier possessing very high gain and excellent stability has been developed. The amplifier consists of a typical magnetic modulator followed by a rectifier filter. The magnitude and polarity of the output is controlled by the DC input.

For comparison purposes, two methods of rectification are being used. In one case, a dual anode zener is used for rectification; in the other, a diode bridge with an RC network inside the bridge is used. Figure 163 is a schematic of the second harmonic modulator with alternate methods of demodulation shown.

Several design features are incorporated to make the amplifier radiation resistant. A tabulation of amplifier characteristics is given in Table 2.

Stamped ring cores of Hy Mu 80 material were selected to provide high gain and good stability. To take into account the increased forward drop through the rectifiers with radiation, a higher gate voltage is used.

Null shift, and gain change are caused principally from change of diode characteristics. Selection of the diodes minimizes this effect. In addition, careful selection of the diodes a design objective was to obtain the highest possible open loop gain with the resultant advantages of increased negative feedback.

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

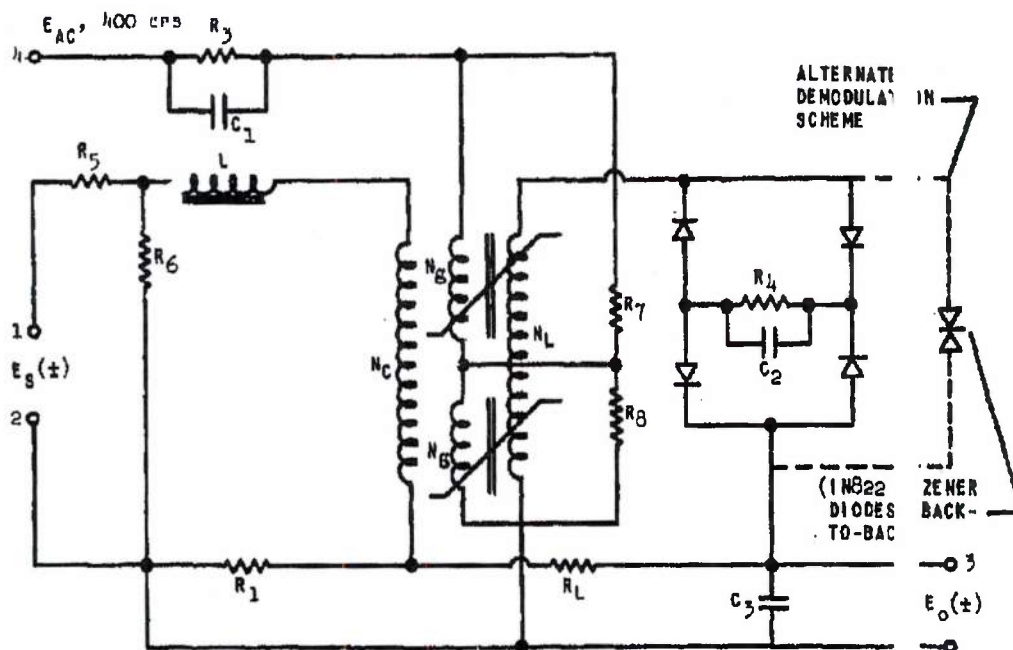
~~ATOMIC ENERGY ACT OF 1954~~

UNCLASSIFIED

*Marquardt*  
VAN NUYS, CALIFORNIA

REF ID: 5876

DIAGRAM OF 400 cps SECOND HARMONIC, d-c MAGNETIC AMPLIFIER



Page determined to be unclassified  
Reviewed Chief, RDD, WHS  
IAW EO 13526, Section 3.5  
Date: MAY 29 2015

MAC A53

UNCLASSIFIED

22G146

-293-

FIGURE 163



~~SECRET RESTRICTED DATA~~

*Monquard*  
VAN NUTS, CALIFORNIA

REPORT 58

~~ATOMIC ENERGY ACT OF 1954~~

TABLE 28

AMPLIFIER CHARACTERISTICS

Characteristics	400-cps Magnetic Amplifier	4800-cps Magnetic Amplifier
Voltage Gain (Closed Loop)	490	20
Load Impedance, ohms	10,000	10,000
Linear Output Range, volts	±2	±40
Linearity, percent	Better than 1	Better than 1
Null Shift with +10% Supply Voltage Variation, millivolts	3 (Output)	7 (Output)
Null Shift with +10% Supply Fre- quency Variation	3 (Output)	3 (Output)
Null Shift with Temperature Variation, 75° F to 180° F	2 (Output)	5 (Output)
Frequency Response (-45° phase shift), cps	5.5	100

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

~~SECRET RESTRICTED DATA~~

*Marquardt*  
VAN NUYS, CALIFORNIA

5876

~~ATOMIC ENERGY ACT OF 1954~~

## (2) Self-Saturating Magnetic Amplifier

A self-saturating push-pull DC amplifier having a good frequency response and stability has been developed. To provide the desired gain bandwidth figure, a supply frequency of 4800 cps is used. Cores were selected of 1 mil Hy Mu 80 material to provide high ampere turn gain. A large amount of negative voltage feed back provides good null stability. To compensate for increased forward drop in the diodes with radiation, a higher gate voltage is used. The use of a bridge circuit serves to reduce diode leakage. Figure 164 is a schematic of the push-pull amplifier. Characteristics of the amplifier are given in Table 28.

### Degradation Tests

Tests simulating diode degradation were conducted on all amplifier types. Degradation in the form of increased forward drop was simulated by inserting a battery in series with the diodes. Reverse leakage was simulated by placing a resistor across the diode.

The 4800-cps DC amplifier uses eight diodes per assembly; however, only four of the eight are in sensitive circuit positions that may be affected by radiation. Diode degradation information taken from the earlier radiation tests (August, 1961) indicate an increase in forward drop of from 2 to 3 volts, and a reverse leakage of 20 to 100 microamperes in the ZJ 225 diode, depending upon the diode selection. A case where the forward drop does not occur uniformly in all diodes (nontracking) is simulated by placing a battery in series with only one diode, or a maximum condition of unbalance when a battery is in series with 2 diodes (same amplifier). This case represents a more severe condition under radiation.

The modulator-bridge rectifier amplifier uses four diodes, all of which are in positions sensitive to degradation. Radiation data previously taken indicate a forward drop increase of from 1.0 to 1.5 volts, and a peak leakage current of 10 to 20 microamperes for the currents and voltages that exist in this circuit. Maximum null shift occurs when the forward drop increase is not uniform in all diodes. Such a condition is simulated by inserting a battery in series with only one diode.

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date:

MAY 29 2015

~~SECRET RESTRICTED DATA~~

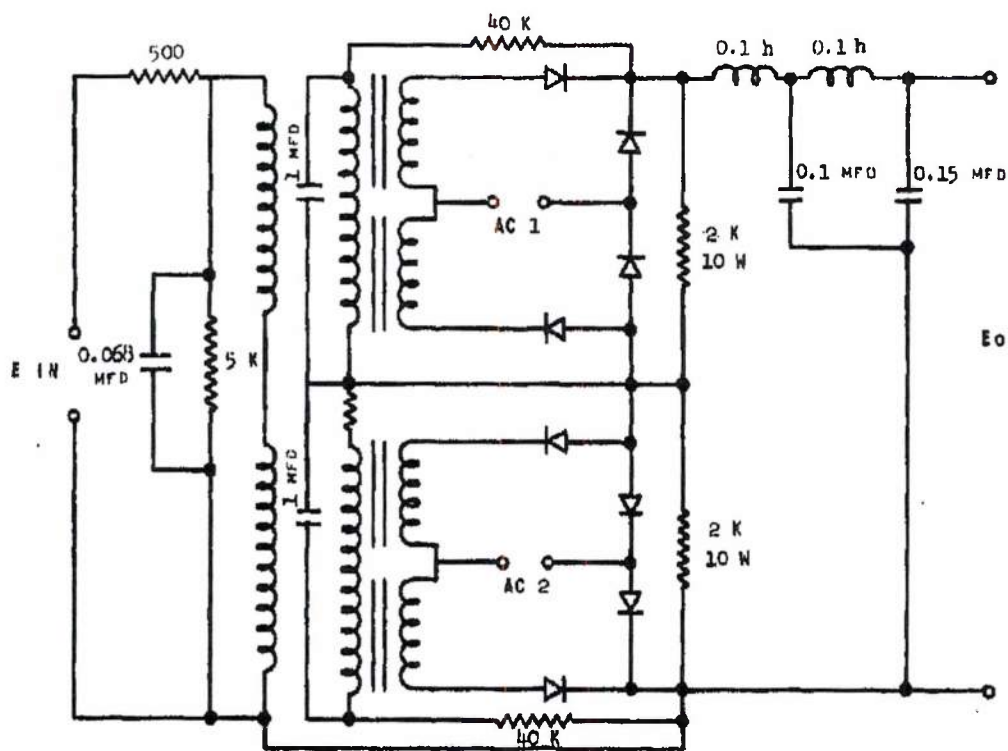
~~ATOMIC ENERGY ACT OF 1954~~

UNCLASSIFIED

*Marquardt*  
VAN NUYS, CALIFORNIA

REPORT 5871

## DIAGRAM OF 4800 cps PUSH-PULL, d-c MAGNETIC AMPLIFIER



COILS = TMC 169A

has been determined to be Unclassified  
Reviewed Chief, RDD, WHS  
IAW EO 13526, Section 3.5  
Date: MAY 29 2015

UNCLASSIFIED

22G148

-296-

FIGURE 64

~~SECRET RESTRICTED DATA~~

5876

~~ATOMIC ENERGY ACT OF 1954~~

The modulator-zener rectifier amplifier is somewhat sensitive to degradation of the zener diode. The August radiation tests on dual anode zener diodes indicated some changes in the zener voltage; however, the change was quite symmetrical. But a marked increase in reverse leakage did occur during these tests. Zener diodes permanently degraded in radiation test level of  $10^{16}$  nvt were tested in these amplifiers, and show a negligible null shift, but a gain reduction of about 15 percent. The August radiation data on these zeners indicated that about 50 percent of the damage occurred between  $10^{16}$  nvt and  $10^{15}$  nvt; therefore, it is suspected that less than 10 percent gain reduction will occur in these amplifiers to  $10^{15}$  nvt.

#### 4.4 RADIATION EFFECTS TESTING

##### 4.4.1 General Status

The detailed results of the irradiation test conducted at General Dynamics/Fort Worth in August 1961 showed that further investigation was necessary in order to isolate and ascertain the effects of gamma irradiation on diode performance. Subsequent testing carried out at the Hughes Aircraft gamma facility showed that certain diodes were more affected by gamma radiation than others. These differences in behavior were finally traced to variations in the manufacturing process.

There followed a detailed screening program to select diodes suitable for use in a set of second generation magnetic amplifiers being prepared for irradiation in the General Dynamics/Fort Worth reactor facility in January 1962.

A total of 160 General Electric ZJ225 thin-based diffused-silicon diodes were obtained. The diodes were divided into three groups, representing three different methods of manufacture. Each group was then subjected to a series of tests designed to eliminate those diodes least suited for use in a high radiation environment.

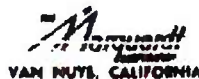
DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~



~~SECRET RESTRICTED DATA~~



REPORT 5876

~~ATOMIC ENERGY ACT OF 1954~~

Each group first underwent elevated temperature tests (125° F and 165° F). The groups were then irradiated with a cobalt-60 source in the Marquardt Radiation Effects Laboratory, at about  $2 \times 10^5$  R/hr of gammas. Finally, each batch received  $\sim 10^{12}$  nvt (fast) at the Atomics International KEWB facility.

The diodes chosen for use in the test amplifiers were selected on the following basis:

Among Groups

Those groups that exhibited least absolute leakage current,  
Those groups that exhibited least inverse current spread  
within a group.

Within a Group

Those diodes that exhibited least tracking spread,  
(current vs. voltage).

In general, none of the diodes subjected to gamma radiation alone or gamma and neutron radiation (in the KEWB facility) displayed the large inverse leakage currents typical of the original set of diodes used in the August irradiation tests. It is estimated that the second generation amplifiers, using carefully selected components, will suffer a gain reduction of less than 10 percent from the fast neutron dose of  $10^{15}$  nvt that they will receive in January 1962.

4.4.2 General Dynamics Test

Preparations for the General Dynamics tests began in May 1961, in close cooperation with the Fort Worth reactor facility staff. The following items were included in the irradiation program:

- (1) Zener diodes
- (2) ZJ225 General Electric diodes
- (3) Diodes, Inc. thin-based silicon diodes
- (4) Motorola thin-based silicon diodes
- (5) Mylar capacitors
- (6) Silver mica capacitors

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

~~SECRET RESTRICTED DATA~~

*Marquardt*  
VAN NUYS, CALIFORNIA

PORT 5876

~~ATOMIC ENERGY ACT OF 1954~~

- (7) Magnetic cores (Delta max, 2-mil diam. winding; H; Mu 80-1 2-mil diam. winding)
- (8) Resistors (wire wound)
- (9) 4800-cps magnetic amplifiers
- (10) 400-cps magnetic amplifiers
- (11) High-gain magnetic amplifiers
- (12) Magnetic voltage reference

The components and circuits were assembled on special aluminum grids supplied by General Dynamics. These grids were then installed in an environmental chamber, which was maintained at a constant temperature of 100°F throughout the irradiation. Figure 165 shows the data handling equipment used to check the circuits for proper operation after installation in the chamber.

The test components were exposed to an integrated neutron flux of  $\sim 10^{16}$  nvt over a period of 49 hours.

The reactor power was programmed as follows:

Time (hours)	Reactor Power (KW)	Flux ( $E > 0.33$ me)
0 - 4	5.3	$3.5 \times 10^8 n$
4 - 34	140	$9.2 \times 10^9 n$
34 - 49	2500	$1.7 \times 10^{11}$

Preirradiation and post-irradiation data, as well as data accumulated during the irradiation period, have been analyzed and are summarized in Section 4.3.4 of this report.

#### 4.4.3 Gamma Irradiations of Magnetic Amplifier Components

On 13 September 1961 a group of 20 General Electric ZJ20 thin-based silicon diodes, which were left over from General Dynamics irradiations in August, were irradiated in the 500-curie, cobalt-60 gamma source at Hughes Aircraft Company. The purpose of the test was to determine whether the reverse characteristics of the diodes were affected by gamma fluxes of  $10^5$  to  $10^6$  R/hr at ambient temperatures. The results showed that certain diodes failed rapidly in the reverse direction as a result of gamma radiation only.

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

MAY 29 2015

UNCLASSIFIED

*Marquardt*  
VAN NUYS, CALIFORNIA

REPORT

376

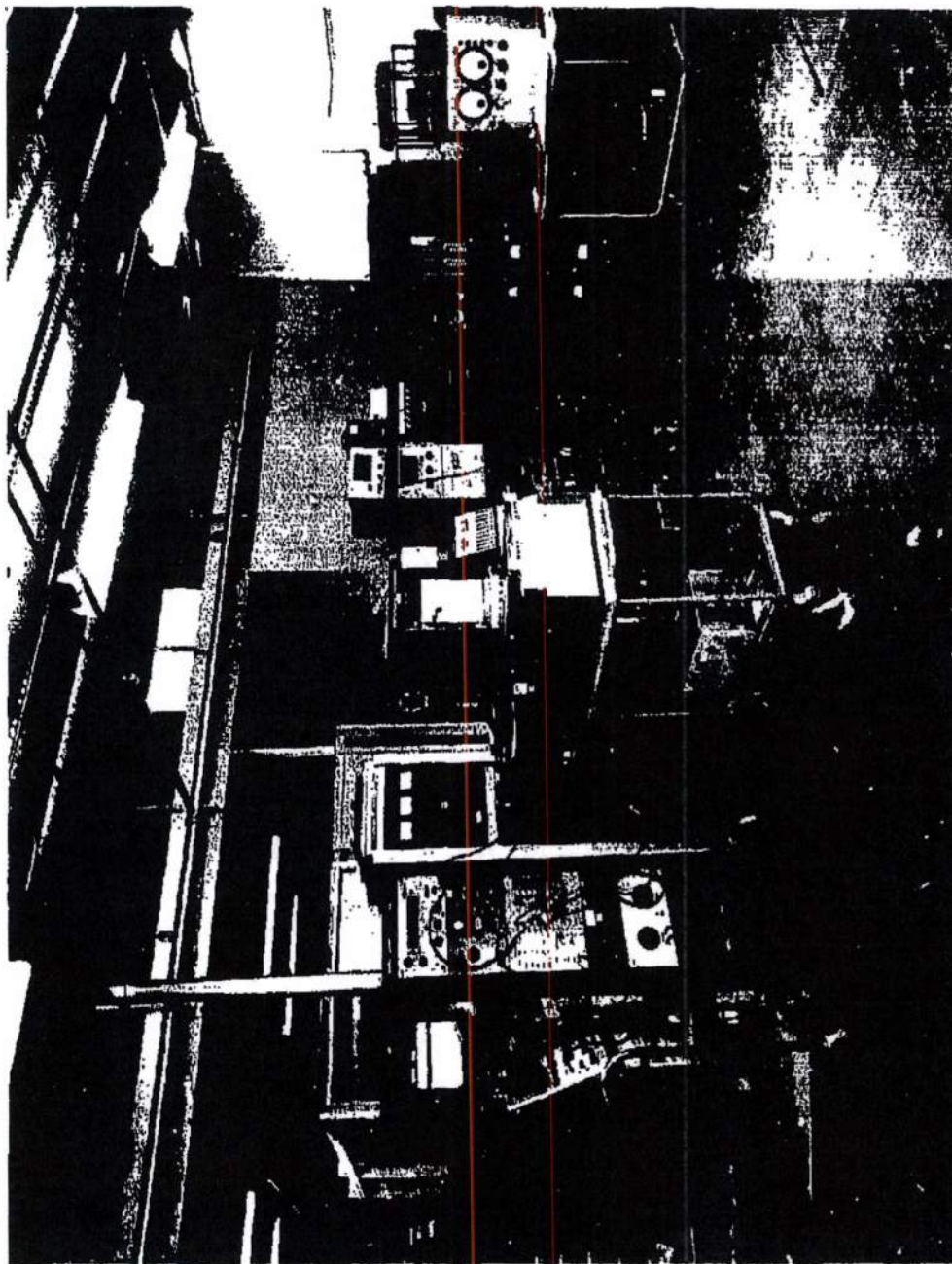


FIGURE 165 - Data Handling Equipment Used to Check Circuits

MAC 2437

UNCLASSIFIED



~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

Following these tests, a 105-curie, cobalt-60 gamma source was purchased and installed in the Marquardt Radiation Effects Laboratory for the purpose of screening magnetic amplifier components suspected of being sensitive to gammas. During the period from 15 November to 22 November 1961, a total of 158 diodes and 7 capacitors scheduled for the January 1962 General Dynamics irradiations were tested in gamma fields up to  $1.7 \times 10^5$  R/hr.

#### 4.4.4 Low Level Neutron Irradiations of Magnetic Amplifier Components

As further check on the radiation resistance of magnetic amplifier components, arrangements were made with the Atomic Energy Commission and Atomics International for the use of the KEWB reactor for the purpose of irradiating diodes in a combined neutron and gamma field. The fast neutron dose ( $E > 2.9$  Mev) was specified to be approximately  $10^{12}$  nvt. A dosimeter run using sulphur and gold foils was made at the KEWB on November 1961 using the same setup that would be used for the tests. In addition, several diodes were included to check their induced activity.

The preliminary test showed sufficient induced activity in the diodes to require special handling although the entire assembly was shielded with cadmium. The sulphur dosimeters yielded an average neutron flux ( $E > 2.9$  Mev) of  $1.7 \times 10^5$  neutrons/cm<sup>2</sup>/watt. On 7 December 1961, 126 General Electric diodes were irradiated for a period of 3 hours and 26 minutes at a power level of 480 watts. In addition to sulphur and gold foils, gamma dosimeters were included to determine the integrated gamma dose. Test runs were made on individual reverse characteristics before, during, and after the run. In addition forward curves were taken on every fifth diode during the run. Dosimetry results from the sulphur foils showed an average integrated neutron flux ( $E > 2.9$  Mev) of  $1.33 \times 10^{12}$  nvt.

#### 4.4.5 1962 Irradiation Program

This company, in conjunction with the Chance Vought Corporation, is making preparation for testing second generation magnetic amplifier circuits at the General Dynamics/Fort Worth reactor facility. These preparations include the mounting of test amplifiers and experimental General Electric ZJ225 diodes on General Dynamics-furnished expanded aluminum sheets, preparation of cables, and data handling equipment. The integrated neutron flux is expected to be a minimum of  $10^{16}$  nvt ( $E > 0.33$  Mev). These circuits and components will be irradiated at ambient temperature. This work is proceeding according to schedule.

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~



~~SECRET RESTRICTED DATA~~

REPORT 587

~~ATOMIC ENERGY ACT OF 1954~~

## 5.0 FLIGHT ENGINE FACILITY AND TEST PLANNING

Test facility planning during FY 1961 has included site location studies, economic studies of air heater and air supply system alternates, design criteria revisions, refined facility cost estimates, and operations and maintenance studies. In addition, the Underground Air Storage (UAS) Experiment achieved important milestones, such as core drilling program completion, final pilot chamber site selection, chamber design completion, fabrication and construction specifications preparation, and complete instrumentation and data reduction system design.

### 5.1 FACILITY DESIGN STUDIES

#### 5.1.1 Flight Engine Ground Test Facility Site Location

A review of potential facility sites was conducted to assure that the underground exploration program for the UAS Experiment would cover sufficient area to be applicable to any feasible Flight Engine Ground Test Facility site selection. As the cost of the air supply line between the UAS chamber and the test point is relatively high, it is very desirable to locate the UAS chamber close to the Facility test point. The review of potential sites was concluded, with four sites being selected for study. The area investigated and the four locations considered are shown in Figure 166.

Site P-1, which is 8,500 feet from Tory II test point, was considered because it permits unrestricted deployment of personnel around the test point with no effect from Tory IIC operations. Dr. J. C. Manning, consulting geologist, indicated that there is a strong possibility that suitable rock exists at this point.

Site P-2, in the amphitheater, was recommended by the United States Geological Survey (USGS) as a desirable site for a full-scale UAS chamber. Shadow shielding afforded by the high terrain surrounding this location provides an additional advantage. The location of site P-2 permits operations without interference from Tory IIC. However, an additional expense for the extension of services is necessitated.

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

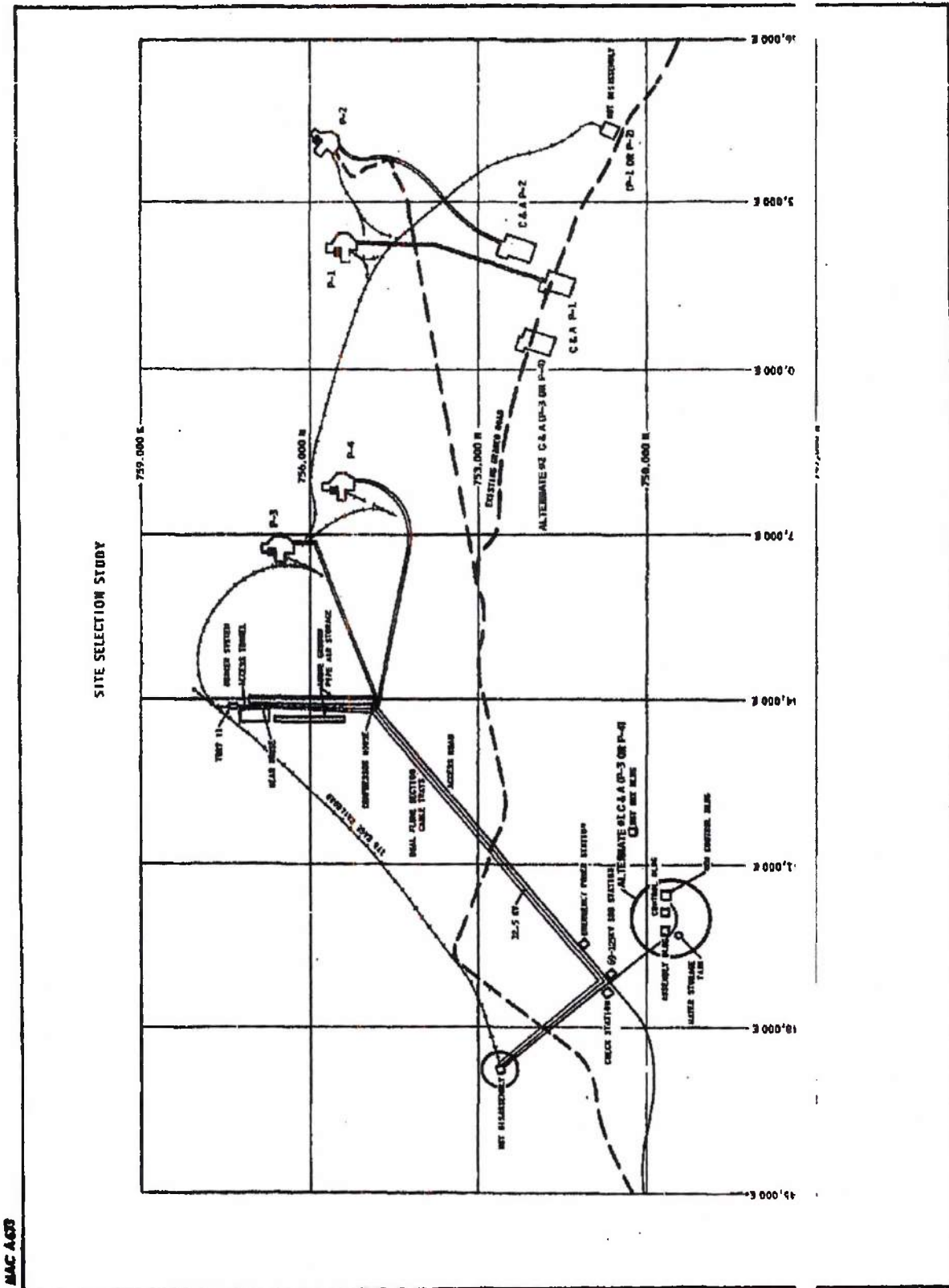
~~ATOMIC ENERGY ACT OF 1954~~

MAY 29 2015

UNCLASSIFIED

**THE Marquardt CORPORATION**  
**VAN NUYS, CALIFORNIA**

REF ID: 5876



MAC A63B

22K16 UNCLASSIFIED

-303-

FIGURE 166



~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

Site P-3, located 3,000 feet from Tory IIC, provides the very minimum practical separation from the Tory IIC test point. Such close proximity offers the advantage of possible sharing of support facilities. However, there is the disadvantage of interference from Tory IIC operation, as well as the uncertainty of site suitability for underground air storage due to visible faulting of the rock structure in this area.

Site P-4 was evaluated in the interest of eliminating some of the operational interference between Site P-3 and Tory IIC. Suitability for underground air storage was also very questionable.

Facilities at sites P-3 and P-4 could be operated from control and administration centers already existing at the general Tory IIC support facility area.

Core drilling operations for the UAS Experiment, discussed in a later section of this report, confirmed that the rock structure in the P-3 and P-4 areas was unsuitable for an underground air storage installation. A test core hole in this area disclosed soft altered rock and suggested this might be a major shear zone.

#### 5.1.2 Facility Performance Criteria

Revisions have been made to the facility performance criteria to reflect new engine test planning, and to obtain a minimal cost test facility. Instrumentation and controls design criteria have been updated in accordance with these performance criteria revisions. The revisions take into account:

- (1) Latest engine test planning, including new engine development schedules and facility utilization
- (2) Analysis of exhaust fission product data from experimental reports
- (3) Use of a standard mission trajectory as the basis for facility testing capability
- (4) Testing of flight type engines only, rather than both boilerplate and flight type
- (5) Change from stored energy heating to continuous heating of test air

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

~~SECRET RESTRICTED DATA~~

5876

ATOMIC ENERGY ACT OF 1954

- (6) Changes in required run time from 25 to 93 minutes
- (7) Change from one to two UAS chambers (for the 90-minute facility)
- (8) Sharing of the Tory hot disassembly building and railroad by the flight engine ground test program
- (9) Sharing of certain service buildings with Tory and minimization of test point exhaust handling equipment

### 5.1.3 Air Supply System

#### Underground Air Storage and Tory IIC Tie Line Study

To determine the cost of sharing the full scale UAS chamber between the Tory IIC facility and the proposed Flight Engine Ground Test Facility, a cost and feasibility study has been made of the required physical pipe connections, based upon an assumed location of the UAS chamber midway between the two facilities.

Sizing of pipe connections for the Tory IIC facility and the flight engine facility was based upon the following needs:

	<u>Tory IIC</u>	<u>Flight Engine Facility</u>
Type of Test	Direct connect	Free jet
Weight Flow	2160 pps	300 pps
Mach Number	3.0	3.0
Inlet Total Pressure, $P_{t_0}$	382 psia	52 psia
Terminal Pressure $P_t$ Tank	772 psia	120 psia
Run Time	23.1 minutes	19 minutes
Altitude	Sea Level	Sea Level
Angle of Attack	Zero	Zero
Type of Day	ANA Cold Day	ANA Cold Day

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

ATOMIC ENERGY ACT OF 1954



~~SECRET RESTRICTED DATA~~

REPORT 76

~~ATOMIC ENERGY ACT OF 1954~~

To meet the Tory IIC requirements, the tie-line from the UAS chamber would require eight parallel runs of 12-inch diameter N-80 steel casing at a cost of \$2,000,000; the tie-line to the Flight Engine Ground Test Facility would require seven parallel runs of the same size and type at a cost of \$1,750,000. The combined cost of connecting the two facilities together will be \$3,750,000. For the case of using a single pipe rather than multiple pipes, the Tory IIC facility would require a pipe 27 1/2 inches in diameter at a cost of \$5,150,000, and the Flight Engine Ground Test Facility would require a pipe 25 1/2 inches in diameter at a cost of \$4,500,000 or a combined cost of \$9,650,000. The storage capacity of the pipes or casing would reduce the UAS chamber cost by approximately 7 percent.

On a comparative basis, the cost of sharing a single full scale UAS chamber would be \$8,750,000 as against \$6,000,000 for an independent chamber to serve each facility. In view of the increased flexibility and service available with independent facilities, the most desirable and most economical arrangement consists of a chamber located as close as possible to each test point.

#### Cross-Country Deployment of Tory IIC Addition

A separate study was made in an effort to increase the utilization of both the UAS chamber in the Flight Engine Ground Test Facility and the air storage addition planned for Tory IIC. Prior to construction, the intent was to realign the planned air storage addition for Tory IIC from a north-south to an east-west direction and interconnect it with the UAS chamber. The Tory I air storage addition, specified at that time, utilized 27 legs of 10 3/4-inch pipe casing approximately 2100 feet long.

This cross-country extension of pipe casing was investigated as a storage supply for Tory IIC, as well as a connecting line from the UAS chamber to Tory IIC air supply system. The feasibility of aboveground installation of pipe over long stretches of undulating terrain has been included as part of the study. The cross-country piping was anchored at both ends and laid in a series of shallow horizontal sine waves and supported by roller and pillow block pipe supports to take up the thermal and pressure expansion.

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

~~SECRET RESTRICTED DATA~~

POST 5876

~~ATOMIC ENERGY ACT OF 1954~~

The number of legs for this cross-country extension is dependent upon the location of the Flight Engine Ground Test Facility. Therefore pipe casing arrays were studied for sites P-2 (10,000 feet from Tory) and P- from Tory). A summary of results of this study is presented in Table 29. The number of legs of 10 3/4-inch OD pipe casing required to provide Tory IIC operating duration equal to that of the current addition was also determined for each facility separation distance. Figure 167 shows the total pressure drop for 6- and 14-leg arrangements and their corresponding lengths measured from the Tory IIC manifold. The study indicates that it would be feasible to extend the Tory IIC air storage addition cross-country to connect the UAS chamber of the Flight Engine Ground Test Facility with realization of the following objectives:

- (1) Economical use of common air storage and compressor systems for the Tory IIC and Pluto facilities
- (2) Adequate separation distances between the two facilities to avoid interference in construction, maintenance, and operations

A comparatively small increment of additional casing (above that planned for Tory IIC) compensates for the airflow pressure drop and would provide the same required run time.

#### Air Heater System

Changes made in the performance criteria are reflected in air supply heater run time and cost. In addition to including both of these factors in the performance criteria change, added emphasis has been placed on heater reliability.

The maximum required continuous heater output, occurring during free jet flow of 3025 lbs/sec at a total pressure of 543 psia and a total temperature of 1060° F, is 720,000 Btu/sec. A heater system comprised of four vitl-ated air heater units, each with its own separate control system, offers the following advantages:

- (1) Increased operational reliability, because malfunction of one heater will have a much reduced effect upon delivered air temperature

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

MAC ACT3

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~



~~SECRET RESTRICTED DATA~~

REPORT 5 '6

~~ATOMIC ENERGY ACT OF 1954~~

TABLE 29  
 CHARACTERISTICS OF CROSS-COUNTRY DEPLOYMENT OF  
 TORY IIC AIR STORAGE ADDITION

Characteristic	Currently Planned Tory IIC Air Storage Addition	Extension to Flight Engine Ground Test Facility Site P-4	Extension to Flight Engine Ground Test Facility, Site P-2
Number of Legs (10 3/4 in. OD by 400 in. Wall Casing)	27	14	6
Length of Legs (ft)	2050	4000	10,000
Air Flow Rate Required from Addition Only (pps)	1122	1122	1122
Air Flow Rate Required from UAS Chamber -Maximum Tory IIC Flow Rate (pps)	2000	2000	2000
Additional Casing Needed to Equal Current Addition (ft)	0	650	4650
Total Casing Length (ft)	55,350	56,000	60,000
Available Tory IIC Run Time from Casing* Only at 1122 pps (min)	5	5	5
Pressure Drop at 1122 pps - Flow from Casing Only (psi)	--	8	128
Pressure Drop at 2000 pps - Flow from UAS Chamber through Casing (psi)	--	170	890
Available Tory IIC Run Time* with UAS Connected (min)	--	27.3	17

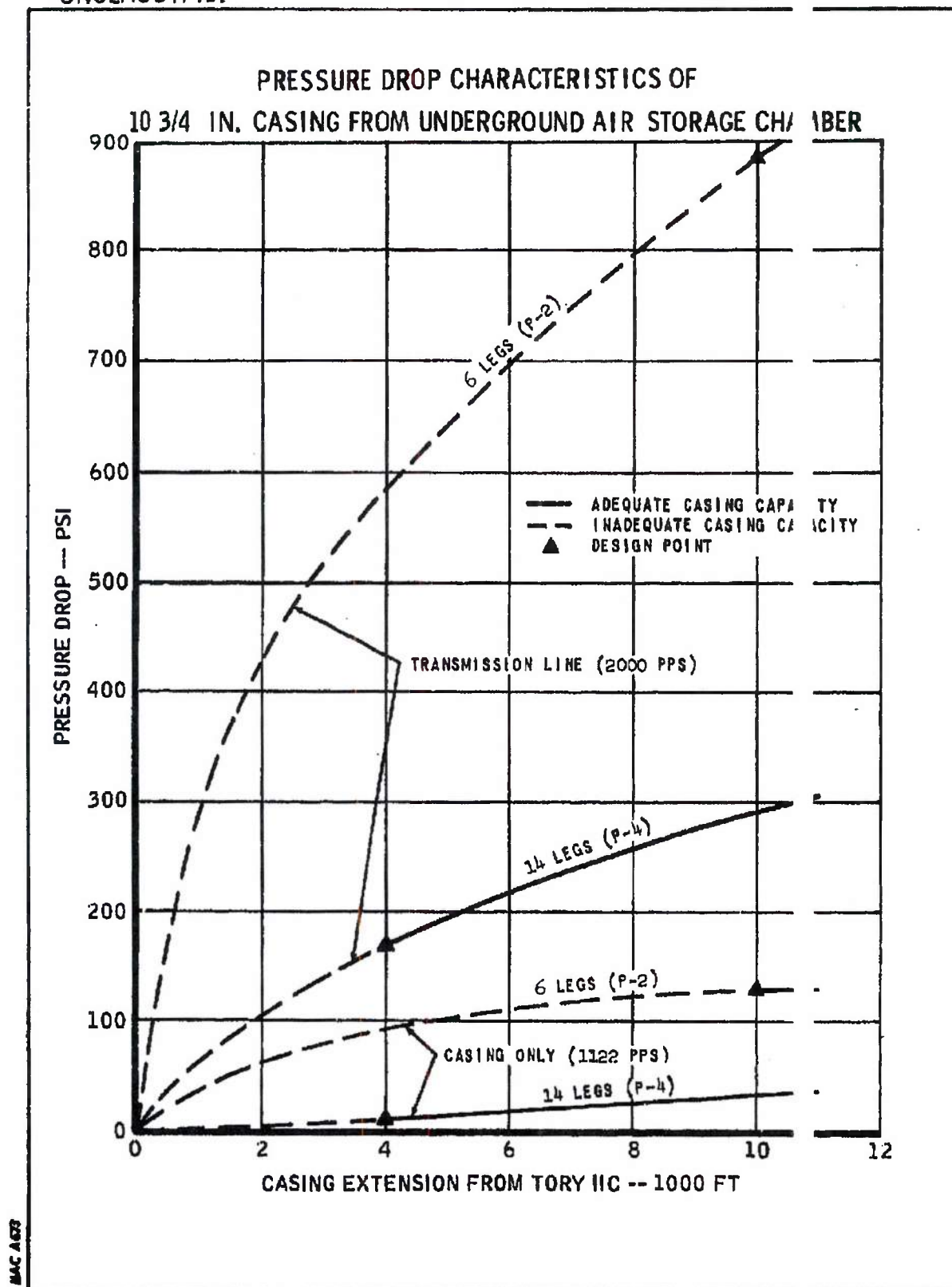
~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

UNCLASSIFIED

THE *Margardt*  
 CORPORATION  
 VAN NUYS, CALIFORNIA

PORT 5876



22K17 UNCLASSIFIED

309

FIGURE 167



~~SECRET RESTRICTED DATA~~

REPORT 58

~~ATOMIC ENERGY ACT OF 1954~~

- (2) More reliable scaling, because the size of each of the four unit more closely approximates the heater successfully tested in the vitiated air heater experiment
- (3) Less severe design stress problems due to reduction of diameter of each high-pressure, high-temperature unit

The preliminary design of the fuel system has been completed. This design provides for the unlikely event of a heater unit flameout by means of component paralleling. One heater unit flameout could produce a momentary air temperature drop of approximately 195° F. It appears that currently considered reactor core materials could cope with a sudden air temperature drop of 200 to 250° F.

Figure 168 shows the preliminary design of the skid-mounted vitiated air heater assembly.

#### Liquid Air Supply System Alternate

Liquid air supply systems have been investigated to determine whether the missile-stimulated increase in this country's liquid air generating capabilities has had an appreciable effect on their cost. Large masses of air can be stored at low pressure in liquid form and then pumped, vaporized, and heated to the pressure and temperature required.

There were three approaches taken in this study:

- (1) Purchase of liquid air from existing Government and private sources with on-site storage and vaporization
- (2) Manufacture of liquid air at a privately owned and operated on-site plant (captive plant)
- (3) Manufacture of liquid air at a Government owned and operated on-site plant

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

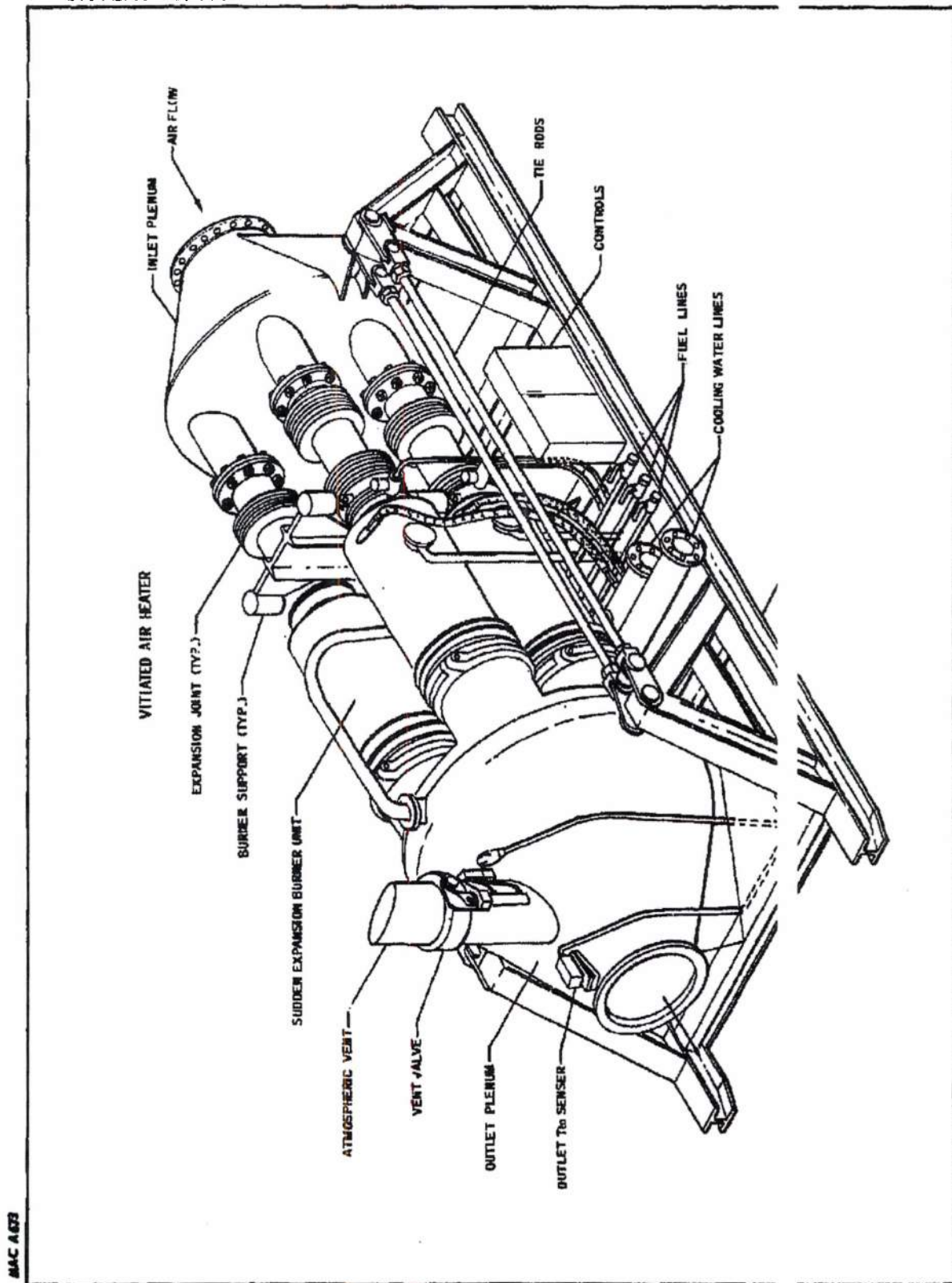
~~ATOMIC ENERGY ACT OF 1954~~

MAY 29 2015

UNCLASSIFIED

THE *Marquardt*  
COMPANY  
VAN NUYS, CALIFORNIA

REPORT 5876



MAC AGO

22K18 UNCLASSIFIED

-311-

FIGURE 168

~~SECRET RESTRICTED DATA~~

ATOMIC ENERGY ACT OF 1954

Estimated costs were made on 4-million, 11-million, and 27-million-pound storage capacities, representing 25-minute, 90-minute, and full trajectory continuous run test capabilities. The 4-and 27-million-pound supply estimates were based on a 5-year life; the 11-million-pound supply on a 2-year life. These systems were compared with the corresponding size of the UAS system. Total costs for the systems are compared in Figures 169, 170, and 171. The performance criteria and estimated costs are listed as follows:

Design Requirements

Total Storage	4 million pounds	27 million pounds
Production Rate	$1.5 \times 10^6$ lbs/day	$1.5 \times 10^6$ lbs/day
Maximum Airflow	3600 pps	3600 pps
Test Air Pressure ( $P_{t_0}$ )	630 psig	630 psig
Air Temperature to Heater	460° R	460° R
Runs per Year	50	25
Life Expectancy	5 years	5 years

Estimated Cost  
(Millions of Dollars)

	<u>4-Million-Pound Storage</u>		<u>27-Million Pound Storage</u>	
	Initial Fixed Cost	Annual Operating Cost	Initial Fixed Cost	Annual Operating Cost
Purchased Liquid Air*	5.54	14.73	10.54	30.09
Captive Plant**	5.54	7.30	10.54	15.01
Government Plant	19.07	2.99	24.02	5.08
Underground Air Storage	6.52	.30	20.24	.13

\* Total existing U.S. production is committed for the next 5 years; operating costs must include amortization of new capacity for the contract.

\*\* Based on guaranteed production for the life of the contract.

~~SECRET RESTRICTED DATA~~

ATOMIC ENERGY ACT OF 1954

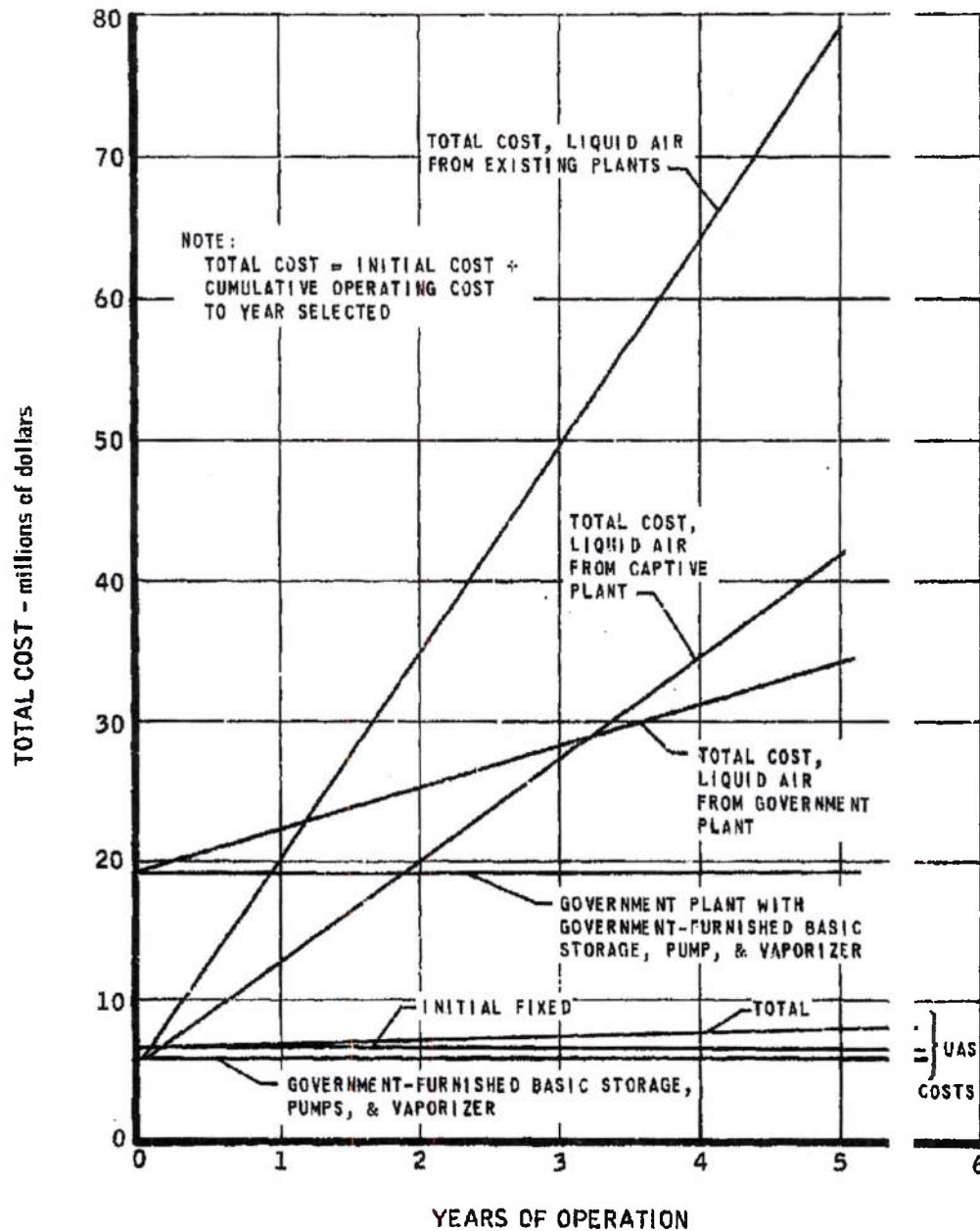


UNCLASSIFIED

*The Marquardt Corporation*  
 VAN NUYS, CALIFORNIA

NT-5876

# COMPARISON OF COST OF FOUR-MILLION-pound LIQUID AIR SYSTEM WITH COST OF UNDERGROUND AIR STORAGE



MAC A67

22K7 UNCLASSIFIED

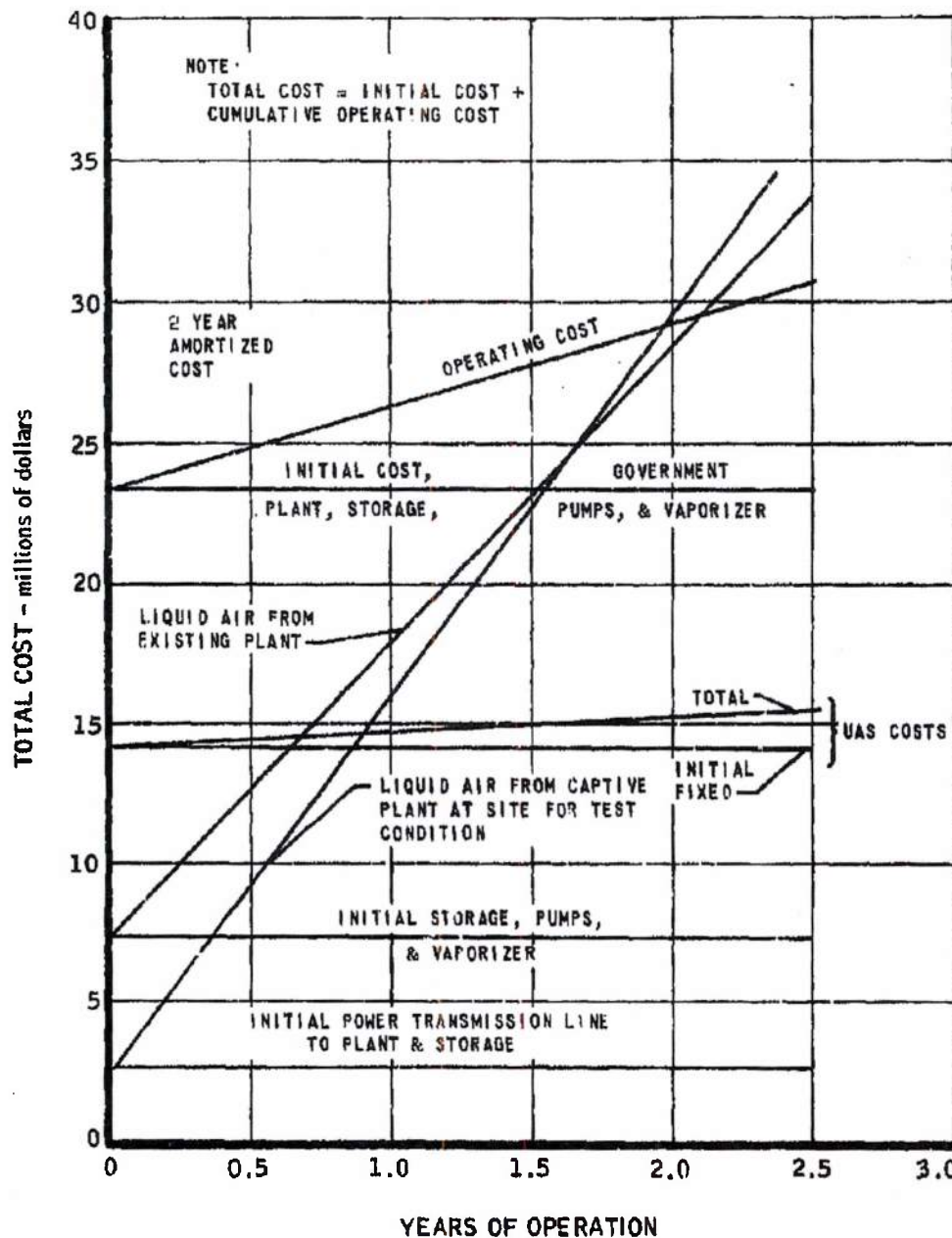
-313-

FIGURE 169



UNCLASSIFIED

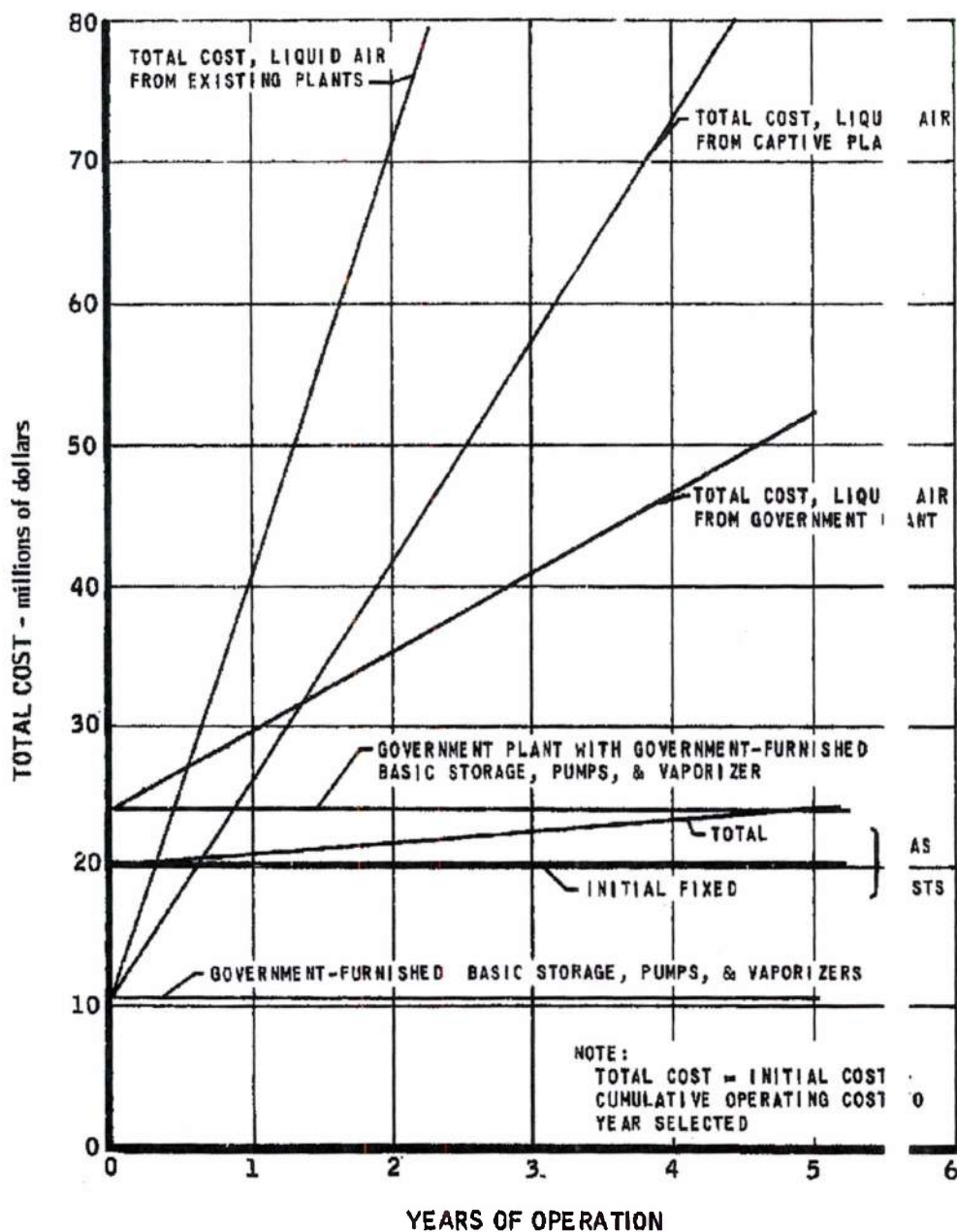
### COMPARISON OF COST OF ELEVEN-MILLION-POUND LIQUID AIR SYSTEM WITH COST OF UNDERGROUND AIR STORAGE



MAC A633

UNCLASSIFIED

# COMPARISON OF COST OF TWENTY-SEVEN-MILLION-pound LIQUID AIR SYSTEM WITH COST OF UNDERGROUND AIR STORAGE



MAC 4673

~~SECRET RESTRICTED DATA~~

ATOMIC ENERGY ACT OF 1954

\* Design Requirements

Total Storage	11 million pounds
Production Rate	$1.836 \times 10^6$ lbs/day
Maximum Airflow	2,000 pps
Test Air Pressure	630 psig
Air Temperature to Heater	460° R
Runs per Year	17.5
Life Expectancy	2 years

Estimated Cost  
(Millions of Dollars)

	<u>Initial Fixed Cost</u>	<u>Annual Operating Cost</u>
Purchased Liquid Air*	7.425	10.50
Captive Plant**	2.6	13.55
Government Plant	23.4	2.95
Underground Air Storage	14.09	.50

In addition to the unfavorable economics, other undesirable characteristics of liquid air storage systems include:

- (1) Transient lag and control difficulties during vaporization, including surging and overpressurization
- (2) Unusually large heat release capacity required for vaporization
- (3) Vaporizer tube burnout and leakage is a definite possibility, with catastrophic failure very probable
- (4) Unusually large amounts of electrical power are required, in excess of currently available power at the Nevada Test Site

\* Total existing U.S. production is committed for the next 5 years; operating costs must include amortization of new capacity for the contract.

\*\* Based on guaranteed production for the life of the contract.

~~SECRET RESTRICTED DATA~~

ATOMIC ENERGY ACT OF 1954



~~SECRET RESTRICTED DATA~~

5876

~~ATOMIC ENERGY ACT OF 1954~~

Cost comparisons of the liquid air system and UAS chamber systems, (Table 30) show the UAS system to be the least costly. Its reliability, due to inherent simplicity and maintainability, further recommend it for the Flight Engine Ground Test Facility.

#### Continuous Air Compressing System

A continuous air supply system with the following performance criteria has been studied:

Test airflow maximum	3,600 pps
Test air pressure, $P_{t_0}$	630 psia
Air temperature to heater	990° R (530° F) temperature out of compressor without after cooler

To meet the above design criteria, the compressing system will require approximately 1,269,000 horsepower. Because of the remote location of the facility, several types of drives were considered, including electric motor (with and without generating plant), diesel engine, gasoline engine, and gas turbine. Both initial and operating costs for each system are shown in Figure 172. Centrifugal compressors with electric drive proved the most economical, with purchased electric power. Comparison of continuous compressing with UAS chamber system costs is shown in Table 30.

#### Aboveground Air Storage System

A cost analysis was performed for an aboveground Tory A-type air storage system, based on the use of threaded oil-well casing to store 15 million pounds of air at a pressure of 3600 psia. This corresponds to a 90 minute run time. A desirable feature of such a system is that large masses of steel are utilized. These masses provide a comparatively large heat sink, which minimizes the air temperature drop during a blowdown test run and reduces the required capacity of an air heating system.

Undesirable features of the system include (1) the system pressure drop during a run because of the great lengths of relatively small-size flow paths, and (2) the high degree of skill and quality control required during installation. Probably the greatest objection to this system is the high cost. The estimated cost of the above-specified aboveground air storage, based on Tory IA and IIC facility costs, totals \$49,535,000. This cost must be compared with the approximate \$9,000,000 cost estimated for a comparable UAS system.

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~



DECLASSIFIED IN FULL

Authority: EO 13526

Chief, Records &amp; Declass Div, WHS

Date: MAY 29 2015

THE  
**Marquardt**  
CORPORATION  
VAN NUYS, CALIFORNIA

~~SECRET RESTRICTED DATA~~

REPORT 587

ATOMIC ENERGY ACT OF 1954

TABLE 30  
SUMMARY OF FACILITY COSTS

Type of Cell	Single Closed Underground	Single Closed Underground	Single Closed Underground	Single Closed Underground	Single Closed Liquid Air Site Mfg.	Single Closed Continuous Compressors
Type of Air Supply						
Usable Air Supply, lbs	3,000,000	11,000,000	20,000,000	20,000,000	3,000,000	Unlimited
Total Air Stored, lbs	4,120,000	15,100,000	27,500,000	27,500,000	4,120,000	Unlimited
Recharge Time, days	3	6	20	20	3	--
Recharge Rate, lbs/day	1,000,000	1,833,333	1,000,000	1,000,000	1,000,000	--
Average Available Run Time (at 1960 pps) mins.	25.5	90	Complete Trajectory	Complete Trajectory	25	Unlimited
Exhaust Handling System	Minimal	Minimal	Minimal	Minimal	Minimal	Minimal
Free Jet Angle of Attack Capability, degrees	+10	+10	+10	+10	+10	+10
New Hot Component	No	No	No	No	No	No
Service Building	Vitiated	Vitiated	Vitiated	Vitiated	Vitiated	Vitiated
Air Heater System	Share with Tory IIC	Share with Tory IIC	Share with Tory IIC	Share with Tory IIC	Share with Tory IIC	Share with Tory IIC
Service Buildings	7	2	1	1	7	1
Number of Runs to Complete Trajectory						
Air Supply System	\$ 8,853,000	\$16,000,000	\$18,173,500	\$18,173,500	\$21,400,000	\$85,780,000
Test Cell Installation and Support Serv.	2,027,200	2,030,000	3,355,000	3,355,000	2,030,000	2,030,000
Exhaust Handling System	238,500	240,000	245,000	245,000	240,000	240,000
Instrumentation and Controls	1,222,600	1,230,000	1,252,700	1,252,700	1,230,000	1,230,000
Hot Component Service Building	--	--	--	--	--	--
Service Buildings	583,300	587,000	599,200	599,200	587,000	587,000
Site Development and Utilities	1,811,000	1,813,000	1,856,900	1,856,900	1,813,000	1,813,000
Required Facility Funding	\$14,735,600	\$21,900,000	\$25,482,300	\$25,482,300	\$27,300,000	\$91,680,000

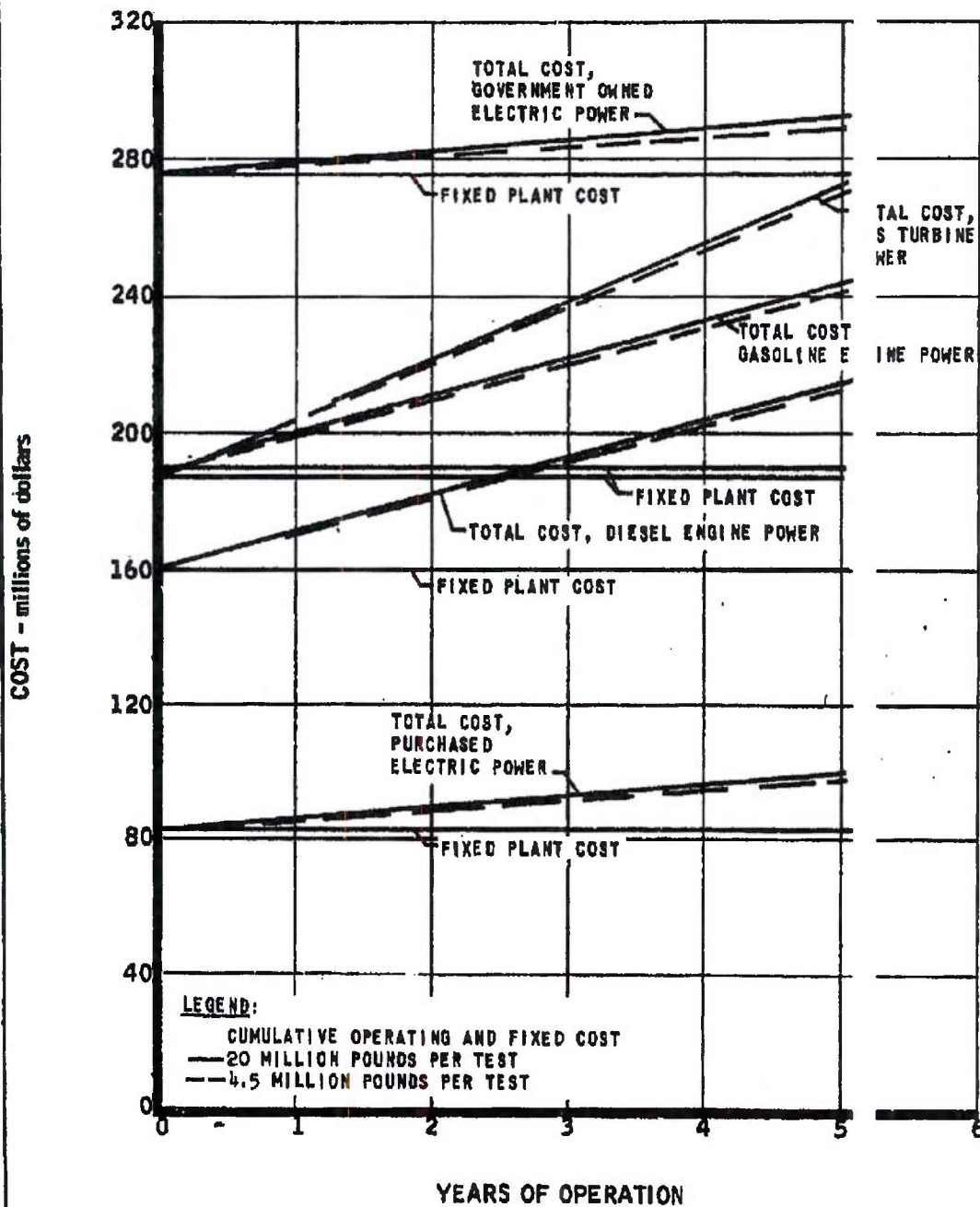
~~SECRET RESTRICTED DATA~~

ATOMIC ENERGY ACT OF 1954

-318-

UNCLASSIFIED

### CONTINUOUS AIR COMPRESSING SYSTEM COSTS



UNCLASSIFIED

N22K36A

~~SECRET RESTRICTED DATA~~

REPORT 587

~~ATOMIC ENERGY ACT OF 1954~~

#### Underground Air Storage Chamber Arrangement

An investigation has been made of one-chamber vs. two-chamber underground air storage of test air for the Flight Engine Ground Test Facility. Concepts of the two concepts were compared, as well as the advantages and disadvantages of each. The two-chamber concept provides much greater operational flexibility, reliability, and maintainability. Valve manipulation will permit charging of one chamber while the other is blowing down during a test, or both may be used simultaneously for long run testing. Figure 173 shows the arrangement and sizing for a 15-million-pound (90-minute run duration) two-chamber air storage system. The separation distance of 835 feet is required to allow full storage pressure in one chamber while the other chamber is at atmospheric pressure.

#### 5.1.4 Instrumentation and Controls

The performance criteria for the Flight Engine Ground Test Facility in the area of data acquisition and facility controls has been revised and updated. Facility instrumentation and controls may be divided into the following system :

- (1) Air pressure control system
- (2) Air temperature control system
- (3) Data acquisition and handling systems

#### Air Pressure Control System

The preliminary design of the air pressure control system was updated and revised in the following areas:

- (1) Pressure reducing valves ( $P_{t0}$  control)
- (2) Low pressure air supply (reactor aftercooling)
- (3) Startup, run, and shutdown control per latest test item planning
- (4) Safety interlocks, based on latest test point operational analysis, use of the vitiated air heater system, and Pluto engine ground control system definition.

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~



MAY 29 2015

THE *Marquardt*  
CORPORATION  
VAN NUYS, CALIFORNIA

PORT 5876

UNCLASSIFIED

TWO - CHAMBER UNDERGROUND AIR STORAGE



PRESSURE  
3600 PSI

STORED AIR  
15,000,000 POUNDS

MAC ACR

Reference: 232-4043-32B

22K22

UNCLASSIFIED

-321-

FIGURE 173



~~SECRET RESTRICTED DATA~~

REPORT 51 6

~~ATOMIC ENERGY ACT OF 1954~~

### Air Temperature Control System

The air temperature control system has been designed to fulfill the main objectives: (1) to permit reasonably accurate transient programming of air temperature, (2) to provide temperature stability during steady state operation, (3) to maintain uninterrupted delivery of heated air to the test item with either manual or automatic time-temperature programming, and (4) to prevent an inadvertent heater control failure from either damaging the reactor or seriously disrupting the test.

The temperature control system has been designed for use with a four-burner vitiated heater. Each of the four burners is provided with a separate automatic temperature controller, thereby assuring that the malfunction of any one burner control system will not cause all burners to malfunction or flame out. Safety interlocks have been incorporated to assure sequential, safe, and automatic operations during startup and shutdown procedures.

### Data Acquisition and Handling

The acquisition of data during a test mission will be provided in the form of magnetic recordings by a multiplexed pulse-duration-modulated (PDM) signal telemetering system. The data acquisition system will gather 86 channels of information from the test cell and 86 channels of information from the various controllers and monitors within the main control room. The two 86-channel groups will be simultaneously recorded on magnetic tape along with the telephone conversation to provide permanent magnetic recordings of raw data signals that can be edited and processed for data reduction and analysis of further processing.

### Facility Cost Estimates

Revisions to the facility performance criteria required corresponding revisions to facility cost estimates. Some of the factors affecting the costs of the facility that were varied for estimating purposes included run time, facility recovery time (recharge rate), and type of air supply.

Run time variations from 25 to 90 minutes, a request for the cost of a facility capable of complete trajectory simulation in one run, together with the alternate air supplies previously reported, produced facility cost estimates summarized in Table 30.

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

~~SECRET RESTRICTED DATA~~

ORT 5876

~~ATOMIC ENERGY ACT OF 1954~~

## 5.2 UNDERGROUND AIR STORAGE EXPERIMENT

Significant progress has been made on the UAS Experiment during the year. The site location survey and core drilling program was completed, chamber site location determined, chamber design finalized, data acquisition system defined and designed, and construction specification and detail drawings completed.

### 5.2.1 Site Investigation

The USGS conducted a mapping program of the NTS 401 area. To provide for the possibility of joint use of the full scale UAS chamber by both Pluto and Tory facilities, this site exploratory program included possible sites close to the Tory IIC facility.

#### Aboveground Area Surveys

A gravity meter survey was completed by the USGS. The survey indicated that there were no rhyolite plugs in the area under consideration, and that the originally planned electromagnetic survey was unnecessary. Compressive strength tests of several samples of surface rock in this area gave values ranging from 8,200 to 42,000 psi, considerably above the 4,000-psi strength required by the UAS chamber design. The gravity meter survey, together with a more detailed visual inspection of the area, detailed the area's filtering system. Due to indications of a highly altered rock zone at one of the considered site locations 3,000 feet east of the Tory test point, core drilling was directed to a more encouraging area.

#### Core Drilling Program

A contract was awarded for core drilling at the Nevada Test Site. Figure 174 shows the core hole locations at which the drilling activity was centered. Typical core samples and views of the drilling operation at the test site are shown in Figure 175. Unconfined compressive strengths and unconfined moduli of elasticity were determined from core samples.

After evaluation of the core drilling program and a report submitted by Dr. John Manning, consulting geologist, a location for the UAS experimental Pilot Chamber was established on the centerline between Core Hole TMC No. 1 and TMC No. 3, 12 feet from the latter. This location is shown graphically in Figure 174.

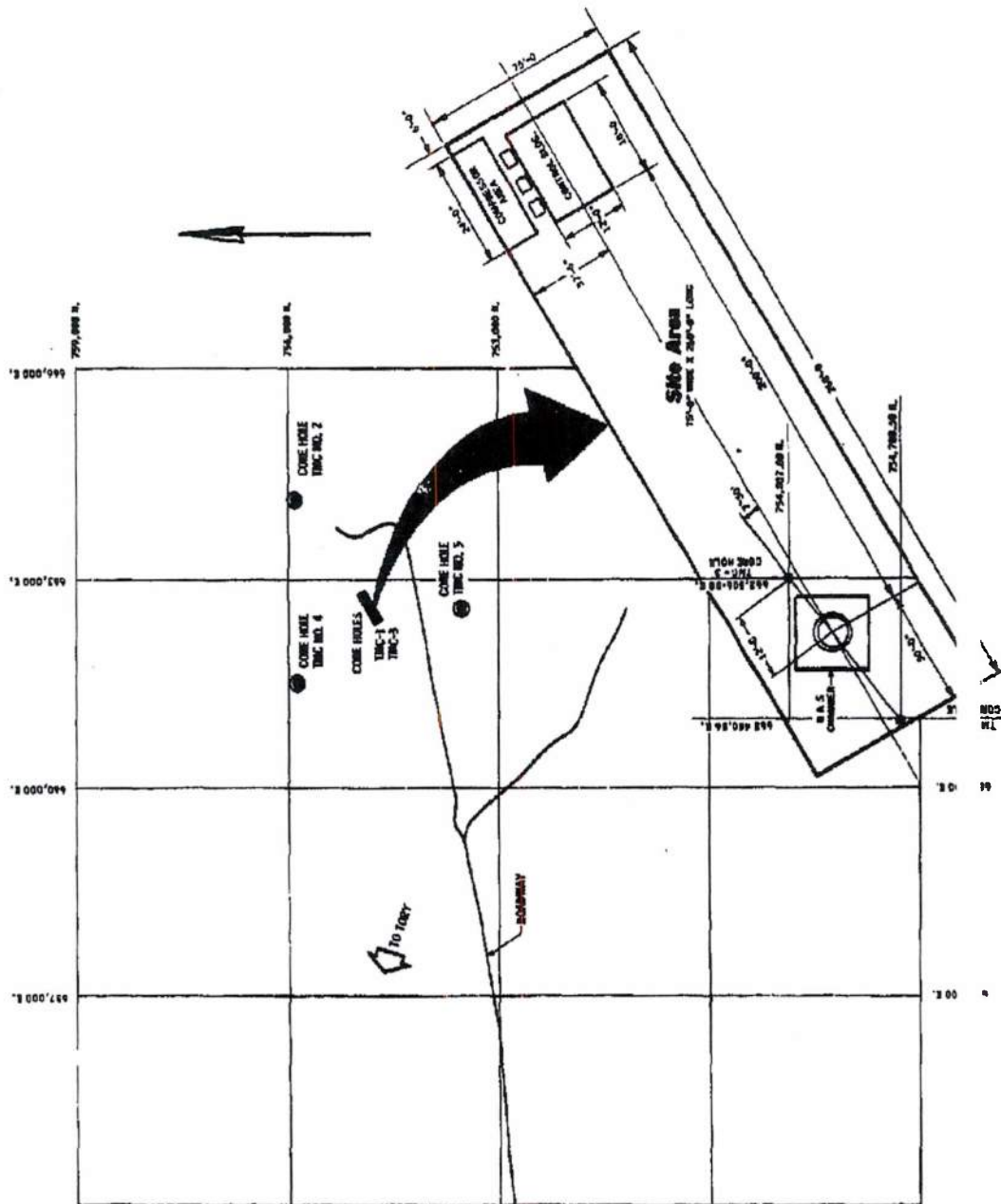
DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

UNCLASSIFIED

UAS CHAMBER VICINITY MAP INCLUDING PLOT PLAN AND CORE HOLE LOCATIONS



BAC AGS

22K19

UNCLASSIFIED

-324-

FIGURE 174

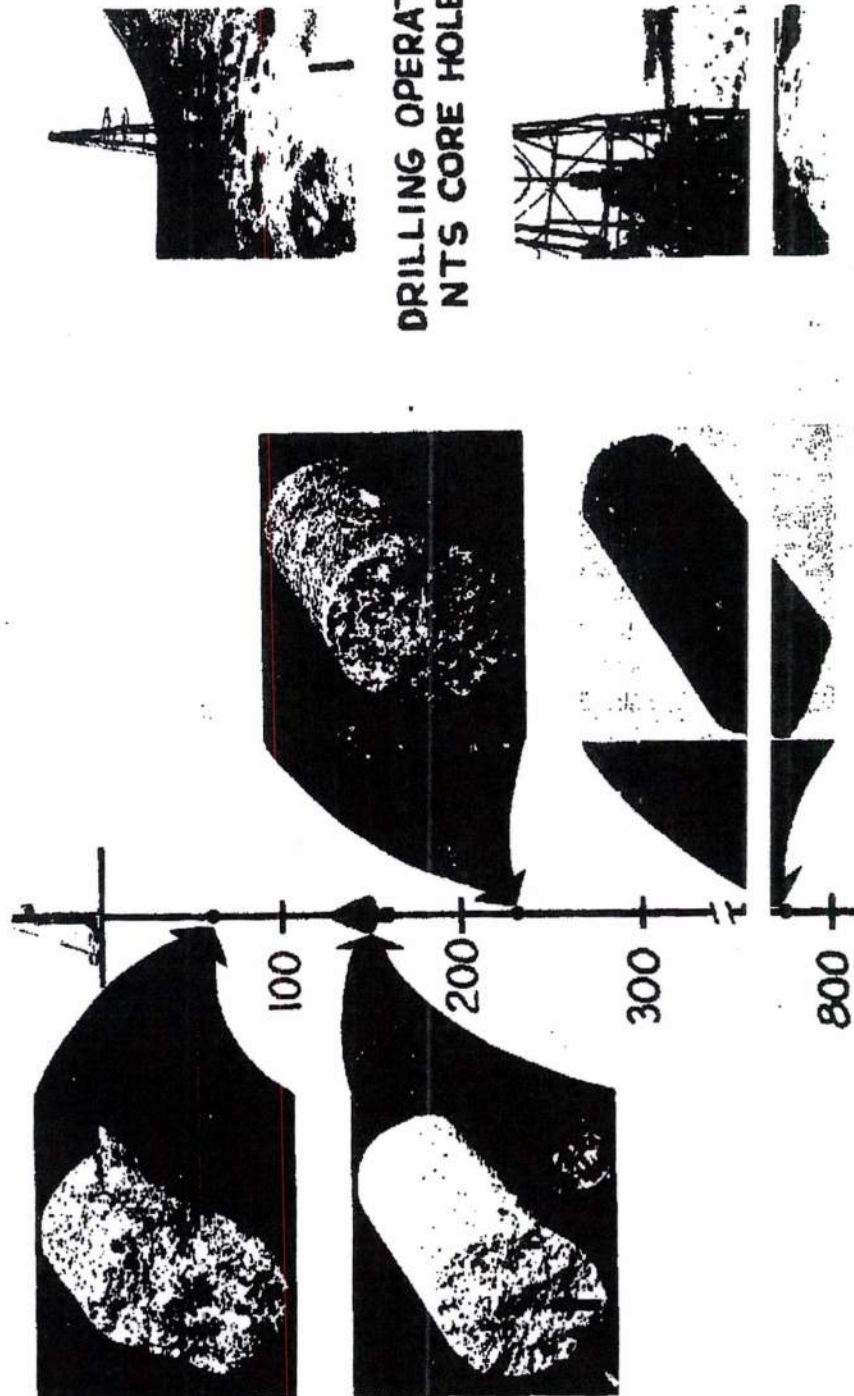


UNCLASSIFIED

SPORT 5876

TYPICAL CORE SAMPLES AND DRILLING OPERATIONS FOR UAS EXPERIMENT

DRILLING OPERATIONS  
NTS CORE HOLE #1



MAC A30

Reference: 232-4134-10A

22K20 UNCLASSIFIED

-325-

FIGURE 175



~~SECRET RESTRICTED DATA~~

REPORT 58

~~ATOMIC ENERGY ACT OF 1954~~

Core Holes TMC No. 1 and No. 3 were drilled approximately at the recommended site for the Flight Engine Ground Test Facility. Their firm dacite rock structure proved satisfactory for underground air storage.

Core Hole TMC No. 2 was drilled in the amphitheater at the north eastern edge of the site area. Individual pieces of rock from this hole exhibited high strength, but the condition of the rock indicated the existence of random oriented, uncemented joints throughout the underground rock mass in this area. The hole was abandoned at 112 feet because the rock was getting progressively worse with depth. In addition, the observed surface faulting in the amphitheater confirmed its unsuitability for underground air storage.

Core Hole TMC No. 4 was drilled to explore the area northwest of the test chamber site. The rock was firm dacite down to a depth of 241 feet where a soft altered zone was encountered. The hole was bottomed in this soft material at 261 feet without any indication of the bottom of the soft zone. This zone of intensive alteration may represent the subsurface trace of a sizable fault. It also gives indication of a major shear zone, eliminating the use of this site for an underground air storage installation.

Core Hole TMC No. 5, drilled to explore the valley area approximately 1200 feet south of Core Hole TMC No. 1, penetrated coarse-grained altered dacite from the surface to the total cored depth of 322 feet. The rock cores were firm and sound, an indication that this area, as well as the area around Core Hole TMC No. 1, should be explored further during the full scale chamber core drilling program.

#### 5.2.2 Chamber Design

All structural and mechanical design for the pilot chamber was completed, and detail drawings were submitted to the AEC for preliminary approval. Figure 176 shows the basic arrangement of the UAS chamber.

#### 5.2.3 Liner-Rock Loading Analysis

During October, 1961, the physical properties of the rock cores taken during the core drilling program of the experiment became available from the laboratory tests. One of these cores, sampled in Core Hole TMC No. 1 at a depth of 309 feet indicated an unconfined elastic modulus of 1,700,000 psi. While this depth is considerably greater than that for the pilot chamber, but less than

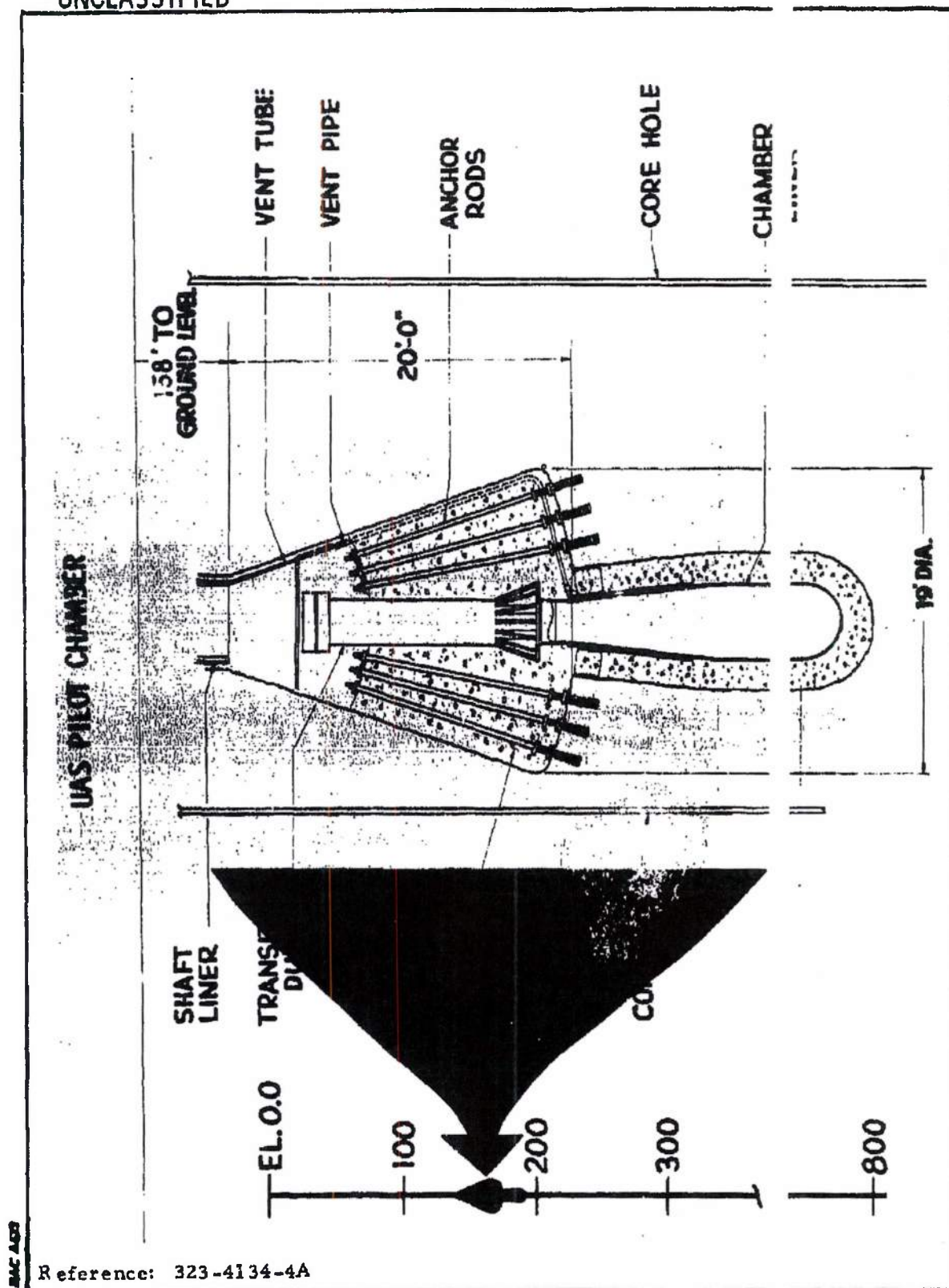
DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WIS  
Date: MAY 29 2015

33

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

UNCLASSIFIED



Reference: 323-4134-4A

22K21 UNCLASSIFIED

-327-

FIGURE 176

~~SECRET RESTRICTED DATA~~

REPORT 5 6

~~ATOMIC ENERGY ACT OF 1954~~

that for the large chamber plug, it indicated that during the construction of the pilot chamber there is a possibility of experiencing a similar modulus in a localized area adjacent to the chamber wall. Therefore, since one of the missions of the experiment is to gain experience prior to full scale chamber design and construction, an analysis was made of the interaction of the liner and the rock in greater detail than that provided by the "cracked rock" analysis previously reported. The basis for this new analysis was an examination of the relative abilities of the chamber liner and the surrounding rock, as parallel load-bearing structures, to back up the chamber pressure load imposed upon them, without the use of the reinforced concrete liner common in tunnel design.

An analytical model (Figure 177) was set up to simulate this interaction and functional relationship. Although the anisotropic characteristics of the rock provide many more (relatively unpredictable) variables than those accounted for in the model, it contains the important functional factors. The basic functional characteristics shown in Figure 177 are the following:

- (1) The liner will pick up a percentage of the radial chamber pressure load and convert it into liner hoop stress.
- (2) The rock must resist the remainder of this load to satisfy equilibrium.
- (3) Liner and rock will expand radially until equilibrium of forces prevails and a new common radius is reached.
- (4) The relative percentages of load carried by liner and rock are determined by the relative stiffness of these two parallel structures, similar to the case of two beams, supported at both ends one above the other, carrying their portion of a single central load in proportion to the ratio of their EI's.

In the case of the liner, its relative "EI" (or resistance to deflection) is a function of (1) its radius, and (2) its elastic modulus (E). The rock stiffness is a function of its elastic modulus in confined state (in-situ E), the depth of the column of rock actually supporting the load, and the load it must bear.

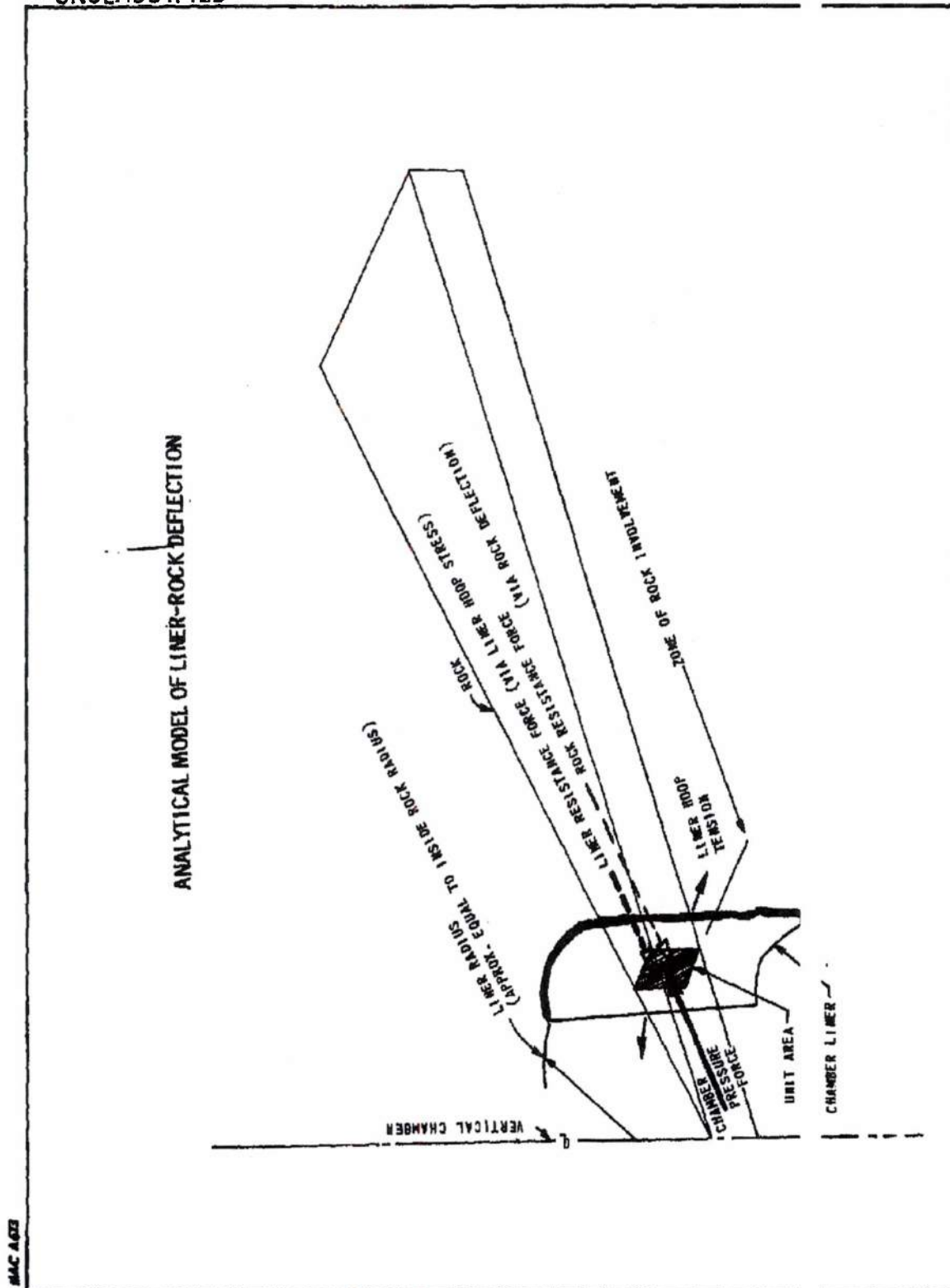
DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~



UNCLASSIFIED







~~SECRET RESTRICTED DATA~~

REPORT 5 6

ATOMIC ENERGY ACT OF 1954

In operation, as chamber pressure increases, the thin liner deflects (stretches circumferentially) to transmit pressure load to the rock, which deflects radially. As the rock deflects, the liner is forced to follow and its hoop stress builds up, thereby picking up a portion of the chamber pressure load. When equilibrium is reached, both the liner and rock have moved the same distance radially and have shared the load between them in some proportion.

It then becomes obvious that, if the rock E is low (it deflects easily), it will increase the stress experienced by the liner. Therefore the design thickness of the liner of a UAS chamber is determined in part by the lowest rock E (in-situ) to be experienced during operation. Thickening the liner decreases its hoop stress by making it relatively more rigid, thereby picking up a greater portion of the pressure load, and in turn reducing the load on the rock and its subsequent deflection. In addition, the larger the diameter of the chamber, the more capable the liner is of resisting the effects of a softer rock, since the radial deflection at the rock and liner is distributed over a larger liner circumference.

The pilot chamber liner thickness of 0.187 inches was selected on the basis of the analysis summarized in Figures 178 through 181. For the analytical model previously described, Figure 179 shows the relationship between the effective pressure load the rock experiences (at equilibrium) vs. chamber pressure. The unconfined E of the analytical model corresponds to the in-situ E that the experiment will reveal. This relationship is plotted for a selection of rock E's from the lowest E anticipated through the largest. At 4000 psi chamber pressure, the liner stress is also designated for each rock E. Since the liner material (T-1 steel) has a minimum yield point of 100,000 psi and an ultimate tensile strength of 135,000 psi, this curve shows that during the experiment the rock can be made to experience a pressure of 3450 psi at a chamber pressure of 4000 psi (if the rock E is 2,500,000 psi) without stressing the liner beyond its elastic limit. This rock loading, though occurring in a 5-foot diameter pilot chamber, closely approximates the loading in the full scale chamber. Figures 178, 180, and 181 provide similar rock pressure vs. chamber pressure data for liners of thicknesses above and below the 0.187 inches selected.

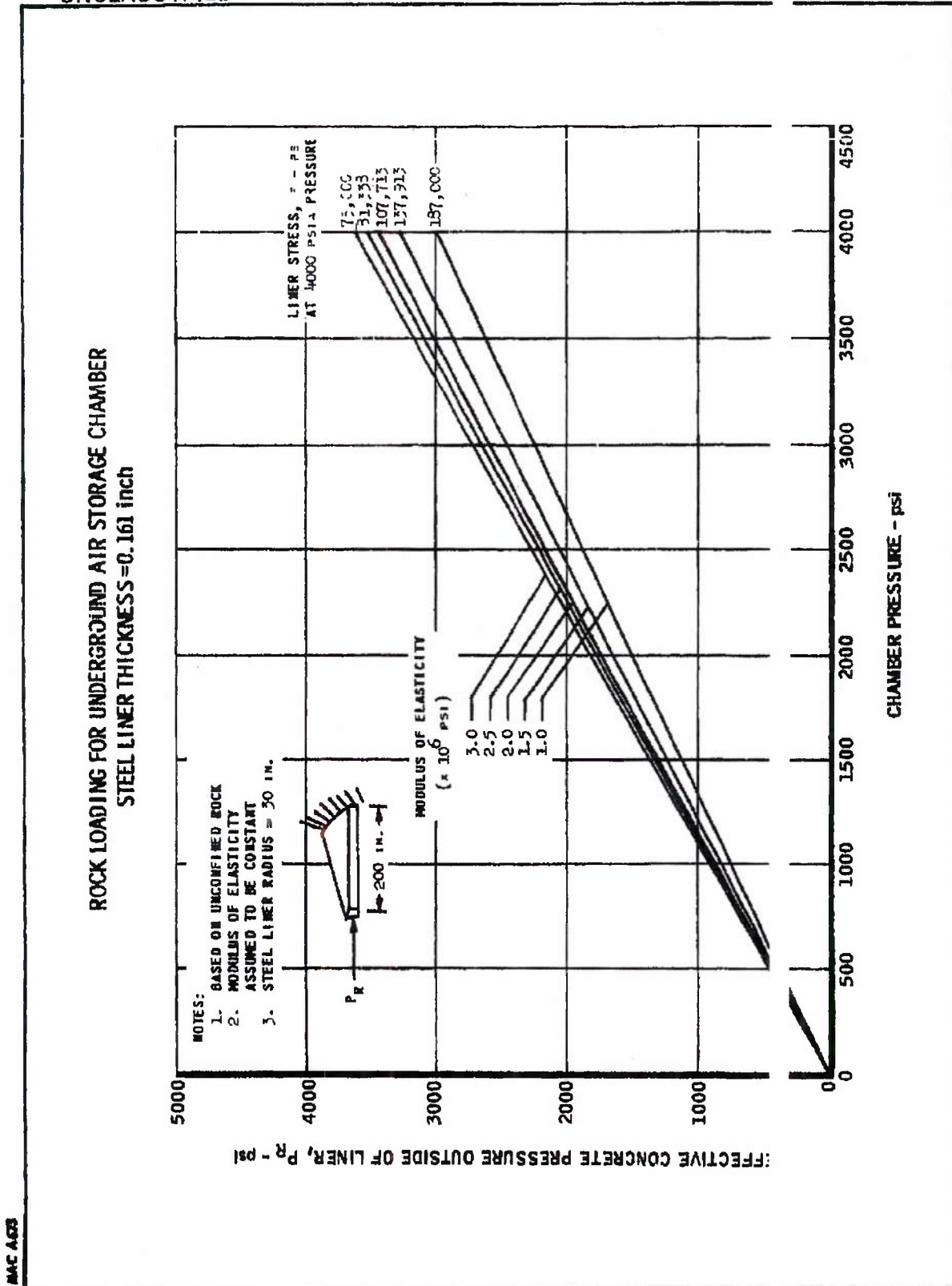
#### 5.2.4 Chamber Construction Specification

The construction specification prepared for the experiment included chamber excavation, structural work, concrete, instrumentation installation, control building, and electrical work. Drawings and specifications were submitted.

~~SECRET RESTRICTED DATA~~

ATOMIC ENERGY ACT OF 1954

UNCLASSIFIED



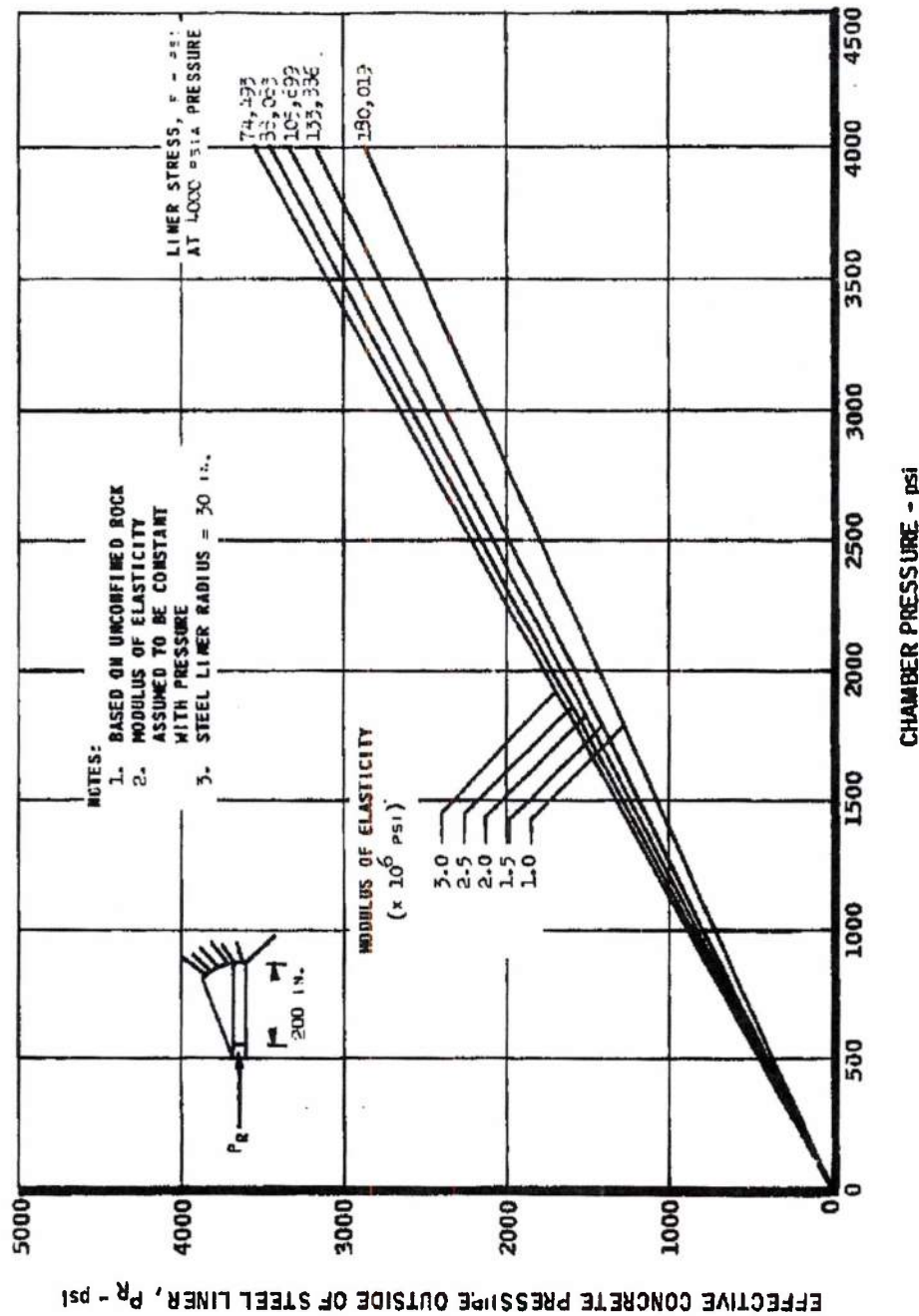
22K10 UNCLASSIFIED

-331-

FIGURE 178

UNCLASSIFIED

ROCK LOADING FOR UNDERGROUND AIR STORAGE CHAMBER  
 STEEL LINER THICKNESS = 0.187 inch



MAC 163

22K11

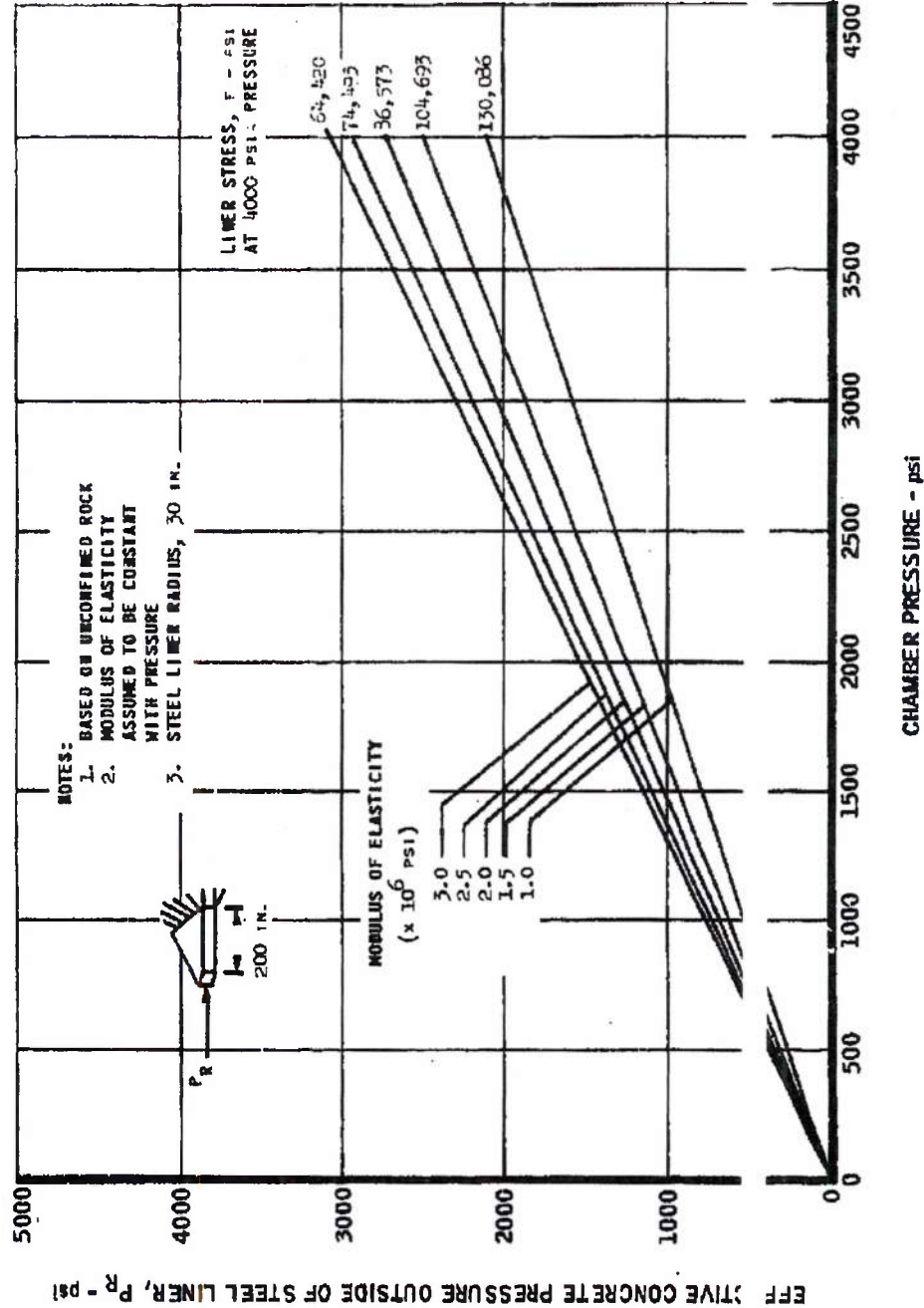
UNCLASSIFIED

-332-

FIGURE E 179

UNCLASSIFIED

**ROCK LOADING FOR UNDERGROUND AIR STORAGE CHAMBER  
 STEEL LINER THICKNESS = 0.438 inch**



MAC 160



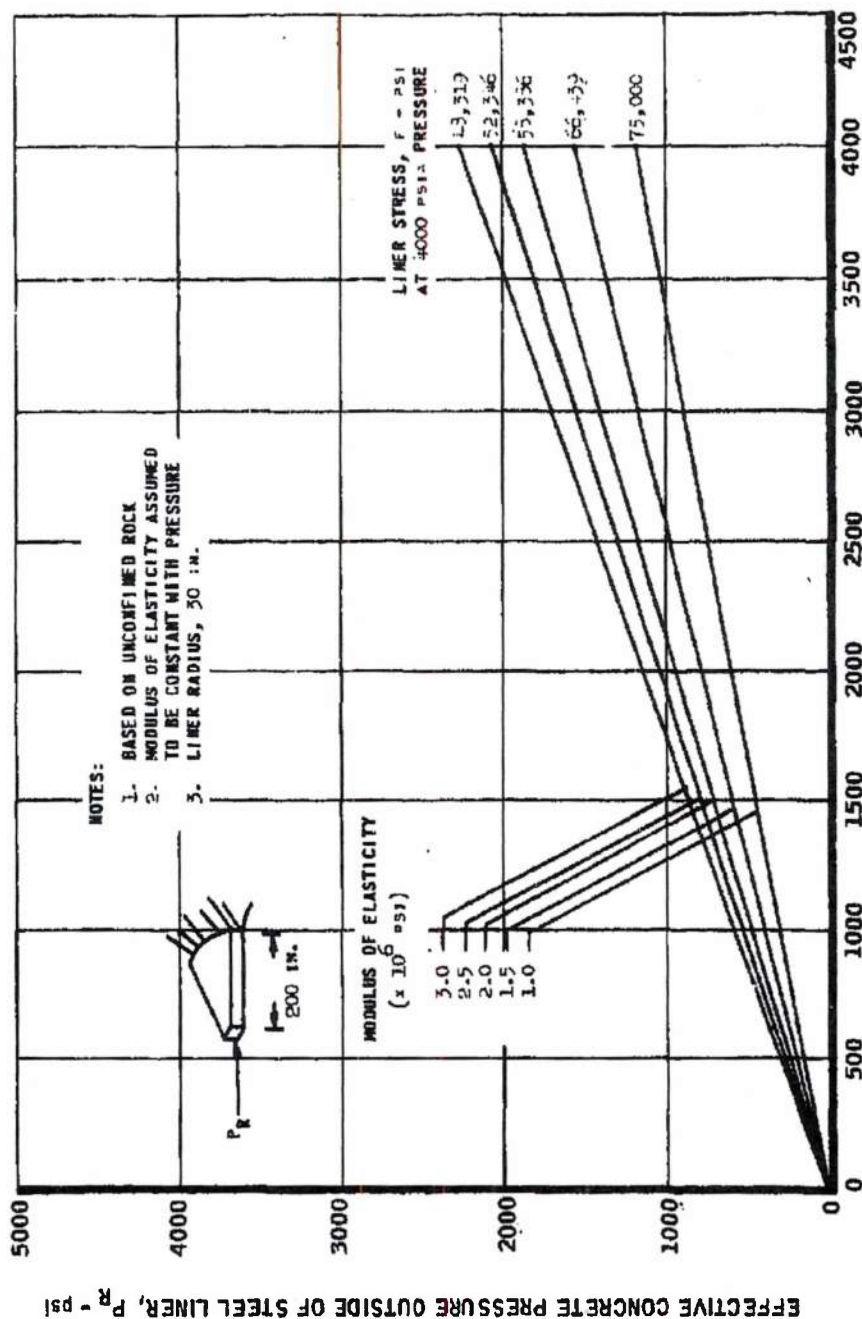
MAY 29 2015

UNCLASSIFIED

THE Marquardt  
 COMPANY  
 VAN NUYS, CALIFORNIA

REPORT 5876

ROCK LOADING FOR UNDERGROUND AIR STORAGE CHAMBER  
 STEEL LINER THICKNESS = 1.12 inches



MAC AGS

22K13 UNCLASSIFIED

-334-

FIGURE 81

~~SECRET RESTRICTED DATA~~



5876

~~ATOMIC ENERGY ACT OF 1954~~

mitted to AEC-LVAO for preliminary approval. The construction specification and detail drawings were then finalized, bound, and resubmitted for final AEC approval prior to release for bidding.

#### 5.2.5 Instrumentation

The instrumentation system, revised according to latest findings, is designed to provide performance data on the chamber liner, surrounding rock, the concrete plug, and the chamber overburden.

Figure 182 graphically displays the types and locations of the various strain and temperature transducers to be installed on the chamber liner, in the concrete, in the rock, and on the anchor rods.

#### Chamber Liner Coating

To help detect evidence of possible nodes in the rock and liner radial deflection during pressurization, three grades of stress-revealing coatings will be applied to the liner inside surface. These coatings will be applied to three separate longitudinal segments of the liner and will cover the anticipated chamber air temperature range from 60° F to 130° F, approximately. In addition to visibly revealing hysteresis in the chamber liner after cycling, these coatings will provide a rough check on strain gage data.

#### Diametral and Axial Strain Measurement

A separate strain measuring subsystem to provide spot-check confirmation of data being accumulated by the liner strain gages has been designed and incorporated into the experimental chamber. The subsystem will consist of diametral and axial strain rods equipped with high sensitivity linear potentiometers. Continuous monitoring of a null balance indicator, capable of being switched between the several strain rods, will provide evidence of strains during all phases of pressurization or pressure cycling of the chamber. The design of the strain rod system has been completed and is as shown in Figure 183.

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

MAC ACT

~~SECRET RESTRICTED DATA~~

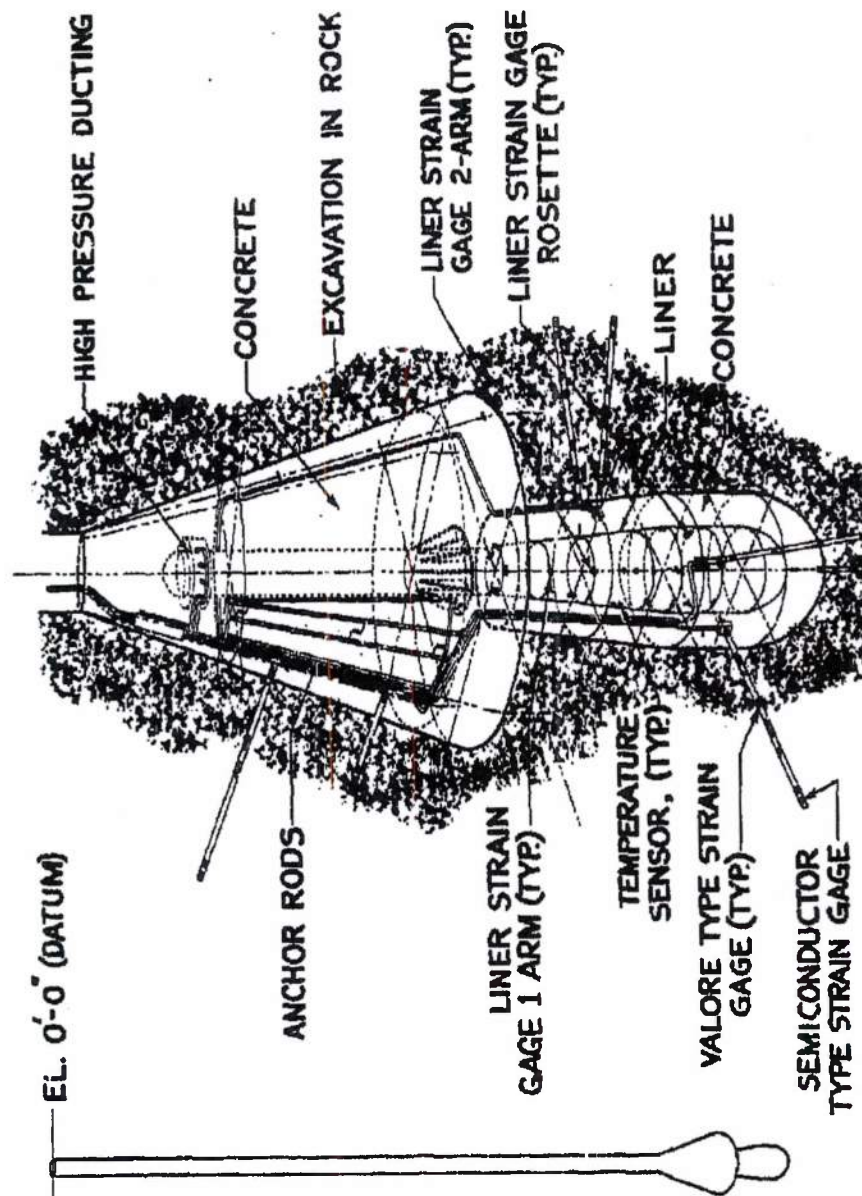
~~ATOMIC ENERGY ACT OF 1954~~

UNCLASSIFIED

THE *Marquardt*  
CORPORATION  
VAN NUYS, CALIFORNIA

REPORT 5871

# UAS CHAMBER INSTRUMENTATION



Reference: 232-4248-5A

22K23

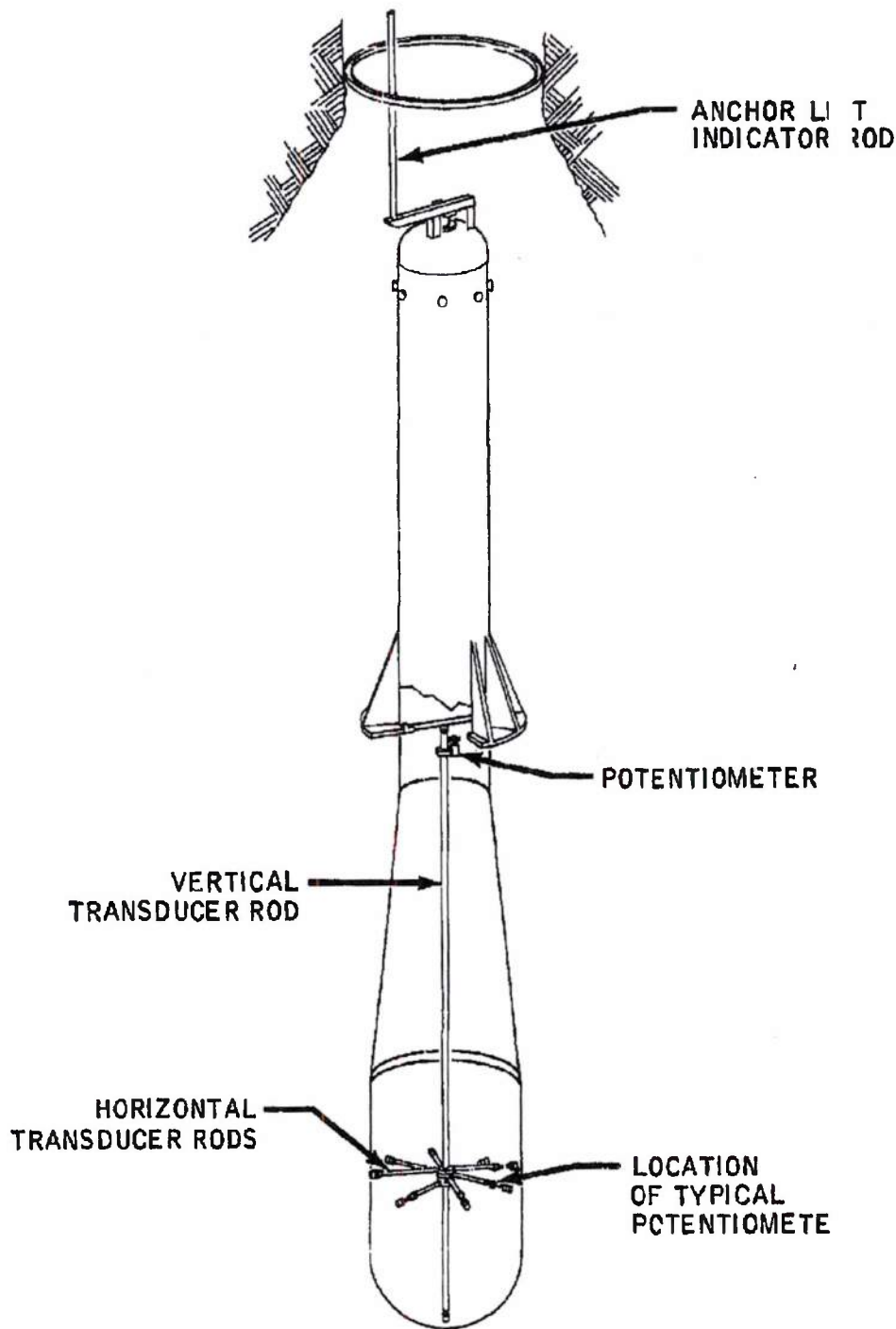
UNCLASSIFIED

-336-

FIGURE 32

UNCLASSIFIED

# TRANSDUCER RODS OF UAS CHAMBER INSTRUMENTATION



MAC AGS



~~SECRET RESTRICTED DATA~~

REPORT 58 5

~~ATOMIC ENERGY ACT OF 1954~~

Chamber Anchor Lift Indicator

During pressurization of the chamber, the pressure loads will be transmitted to the surrounding rock formation. These loads will be transmitted downward through the bottom hemispherical section of the liner, radially through the cylindrical and conical sections of the liner, and upward through the transition section of the liner assembly. The upward load will be through the anchor (plug) to a core of rock above the chamber.

To indicate vertical movement of the anchor, a mechanical indicating device has been designed for attachment at the top of the transition section. This device (shown in Figure 183), elevating a fluid container at the top of the chamber access shaft, will actuate a draft gage type indicator in the control building.

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

~~SECRET RESTRICTED DATA~~

*Marquardt*  
VAN NUYS, CALIFORNIA

REPORT 5876

~~ATOMIC ENERGY ACT OF 1954~~

#### REFERENCES

1. Lawrence Radiation Laboratory, "Tory IIC Data Book," Livermore, California, Revised 12 October 1961, SECRET RESTRICTED DATA.
2. Marquardt Report 5854, "Preliminary Performance Bulletin for the Marquardt Model MA50-XCA Ramjet Engine," 17 July 1961, SECRET RESTRICTED DATA.
3. Marquardt Report 5863, "Preliminary Performance Bulletin No. 2 for the Marquardt Model MA50-XCA Ramjet Engine," 22 September 1961, SECRET RESTRICTED DATA.
4. Marquardt Report 5872, "Preliminary Performance Bulletin No. 3 for the Marquardt Nuclear Ramjet Engine," 1 December 1961, SECRET RESTRICTED DATA.
5. Marquardt Report P3015B, Book I of II, "Aircraft Nuclear Propulsion System Research and Development for 1961," SECRET RESTRICTED DATA.
6. NASA Report TMX-145, "Performance of a Mach 3.0 External-Internal-Compression Axisymmetric Inlet at Mach Numbers from 2.0 to 3.5," by L. E. Stitt and R. J. Salmi, Washington, January 1960, CONFIDENTIAL.
7. Marquardt Report PR 254-19Q, "Aircraft Nuclear Propulsion Systems, Project Pluto, Nineteenth Quarterly Progress Report," 29 April 1961, SECRET RESTRICTED DATA.
8. Marquardt Report PR 254-20Q, "Aircraft Nuclear Propulsion Systems, Project Pluto, Twentieth Quarterly Progress Report," 31 July 1961, SECRET RESTRICTED DATA.
9. Marquardt Report PR 254-21Q, "Aircraft Nuclear Propulsion Systems, Project Pluto, Twenty-first Quarterly Progress Report," 31 December 1961, SECRET RESTRICTED DATA.
10. Chance Vought Report ARDC-TR-59-13, "Final Report, SLAM Nuclear Powered Missile Weapon System Study," Part XIII, "Propulsion," 28 February 1959, SECRET RESTRICTED DATA.

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

DECLASSIFIED IN FULL

Authority: EO 13526

Chief, Records & Declass Div, WIS

Date: MAY 29 2015



~~SECRET RESTRICTED DATA~~

REPORT 51 6

~~ATOMIC ENERGY ACT OF 1954~~

REFERENCES (Continued)

11. Chance Vought Report AER/SLAM-S-250, "Aerothermodynamics for Pluto; Interim Summary Report," 3 October 1961, SECRET RESTRICTED DATA.
12. NACA Report TN2973, "Theoretical Pressure Distributions and Wave Drag for Conical Boattails," by J. R. Jack, Washington, July 1953.
13. University of Illinois, Mechanical Engineering Dept. Report ME TN392- "A Theory for Base Pressures in Transonic and Supersonic Flow," by H. H. Korst, R. H. Page, and M. E. Childs, March 1955.
14. Marquardt Report P3015B, Book II of II, "Aircraft Propulsion System Research and Development for 1961," SECRET RESTRICTED DATA.
15. NASA Report TN D-130, "Use of a Theoretical Flow Model to Correlate Data for Film Cooling or Heating an Adiabatic Wall by Tangential Injection of Gases of Different Fluid Properties," J. E. Hatch and S. S. Papell, November 1959.
16. Marquardt Report 5873, "Preliminary Analysis of Lateral Vibrations of the Pluto Reactor," 15 December 1961, SECRET RESTRICTED DATA.
17. Den Hartog, J. P., "Mechanical Vibration," 3rd Edition, McGraw-Hill Book Company, Inc., New York, 1947.
18. Wachpress, E. L., "Thin Regions in Diffusion Theory Calculation," NUC SCI ENGRG, Vol. 3, pp 186-200, February 1958.
19. Lawrence Radiation Laboratory, Tory IIC Memorandum No. 36, H. Reynolds and M. Uthe, October 1960, SECRET RESTRICTED DATA.
20. AEC Report NYO-3075, "Calculation of the Penetration of Gamma Rays" by H. Goldstein and J. E. Wilkins, New York, 30 June 1954.
21. General Electric Report XDC 61-1-149, "Measured and Calculated Radiation Levels Within and Behind Beryllium Oxide," by P. W. Schrieber and F. D. Kodras, 15 December 1960, CONFIDENTIAL RESTRICTED DATA.
22. Nuclear Development Corporation of America Report NDA 2058-10, "Gamma Ray Penetration in Composite Slabs," M. H. Kalos, March 1957.

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~

~~SECRET RESTRICTED DATA~~

REPORT 5876

~~ATOMIC ENERGY ACT OF 1954~~

REFERENCES (Continued)

23. Atomics International Report NAA-SR-3719, "Grace-I, an IBM 14-709 Program Designed for Computing Gamma Ray Attenuation and Heating in Reactor Shields," D. S. Duncan and A. B. Spier, April 1959.
24. Marquardt Report MR 20,140, "Radiation Analysis and Shielding for the Nuclear Ramjet Engine System," 1 June 1961, SECRET RESTRICTED DATA.
25. Marquardt Report PR 254-18Q, "Aircraft Nuclear Propulsion Systems, Project Pluto, Eighteenth Quarterly Progress Report," 19 November 1960, SECRET RESTRICTED DATA.
26. Marquardt Report MR 5847, "Analysis of the In-Flight Control System for the Project Pluto Engine for the Year 1960," 15 April 1961, SECRET RESTRICTED DATA.
27. BuAer Report AE-61-411, "Dynamics of the Airframe," September 1952.
28. Marquardt Report MR 20,142, "Temperature Sensors," June 1961.
29. Marquardt Report S-209, "Operation of Thermocouples Under Conditions of High Temperature and Nuclear Radiation," 15 June 1961.
30. Marquardt Report S-222, "Performance of Radiation Resistant Magnetic Amplifier Controls Under Fast Neutron and Gamma Irradiation," 30 August 1961.

DECLASSIFIED IN FULL  
Authority: EO 13526  
Chief, Records & Declass Div, WHS  
Date: MAY 29 2015

~~SECRET RESTRICTED DATA~~

~~ATOMIC ENERGY ACT OF 1954~~